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Technical Report 113
Monitoring the Distribution and Abundance of Native Gobies ('o'opu) in Waikolu and Pelekunu Streams on the Island of Moloka'i

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INTRODUCTION

Hawaiian stream systems support a unique fish fauna, found nowhere else in the world. The extreme isolation of the Hawaiian Islands has resulted in an aquatic macrofauna that is low in diversity but high in endemism. The five native gobies, two in the estuary and three in freshwater, each represents a separate genus (Hawai'i Stream Assessment 1990; Kinzie 1988, 1990; Maciolek 1975, 1977a,b). The native gobies ('o'opu) are of marine origin and have retained an oceanic larval life stage. This amphidromous life cycle and the apparently random recruitment back to the streams can affect both species composition and abundance. Once in the stream, the gobies have been shown to have distinct habitat preferences and exhibit a longitudinal separation along the stream gradient (Brasher 1995; Kinzie 1988; Nishimoto and Kuamoo 1991).

The natural variability in distribution and abundance of native 'o'opu is accentuated by the fact that the majority of streams in Hawai'i have been severely altered by humans through diversions, channel modification, siltation and introduced species (Devick 1991; Kinzie 1988; Maciolek 1975, 1977a,b). In 1978 at least 53% of the estimated 366 perennial streams had some type of water diversion and 15% of the streams in the state had been channelized (Parrish et al. 1978). In fact, only 14% of Hawaiian streams today may be considered physically pristine and there appear to be no biologically pristine streams, because at least one introduced species has been found in every stream that has been surveyed (Hawai'i Stream Assessment 1990; Timbol and Maciolek 1978).

The primary threat to native stream gobies throughout the state is the continuing loss and degradation of available stream habitats (Maciolek 1977a, b). In order to properly manage these stream systems, and to evaluate the impact of stream alterations, a better understanding of the baseline conditions in Hawaiian streams is required. The purpose of this study was to establish consistent and reliable survey methods which can be used for monitoring 'o'opu populations, and to provide a thorough description of the distribution and abundance of the three native freshwater goby species : Awaous guamensis ('o'opu nakea), Sicyopterus stimpsoni ('o'opu nopili) and Lentipes concolor ('o'opu alamo'o) in Waikolu Stream and Pelekunu Stream on the Island of Moloka'i . Additional 'o'opu found in Hawai'i but not covered in this study are Stenogobius hawaiiensis ('o'opu naniha) and Eleotris sandwicensis ('o'opu akupa) (See Appendix A for synonyms of all Latin and Hawaiian species names).

Amphidromous life cycle

The native 'o'opu of Hawai'i have an amphidromous life history (McDowall 1988). To complete their life cycle such species must migrate between the stream and ocean (Figure 1). 'O'opu eggs are laid attached to the underside of rocks and boulders in the stream. The eggs hatch and the larvae wash out to the sea. After spending a larval phase of four to seven months as marine plankton, gobies return to the streams as transparent postlarvae (hinana) approximately 2 cm long (Ego 1956; Kinzie 1988; Radtke et al. 1988). Spates (high flood events) have been hypothesized as a cue for both reproduction and recruitment back to the stream (Kinzie 1988), and may play an important role in community structure (Kinzie and Ford 1982).

The factors responsible for stream identification and recruitment (post-larvae returning from the ocean to the stream) are not well understood, but there is no indication that larvae must return to natal streams (Ford and Yuen 1988). Genetic studies suggest that a large proportion of new recruits originate from the same stream. However, adequate mixing occurs between streams so that all are considered to be one population (Fitzsimons et al. 1990).

Erdman (1986) found upstream migration of the goby Sicydium plumieri in Puerto Rico to be triggered by moon phase, but this does not appear to be the case for Hawaiian gobies. It has been reported that 'o'opu may be timing such activities as spawning and return migrations from the sea by cueing on the high flows that occur during spates (Erdman 1986; Kinzie and Ford 1982; Manacop 1953). Postlarval gobies (hinana) were traditionally considered a delicacy by Hawaiians and were caught in great numbers along stream mouths (Titcomb 1972).

'O'opu

Lentipes concolor ('o'opu alamo'o) is the least common goby in Hawai'i (Timbol et al. 1980). Pelekunu Stream and Waikolu Stream are notable for supporting high densities of 'o'opu alamo'o (Hawai'i Stream Assessment 1990). Mature alamo'o typically reside in the middle to upper reaches of streams, although they may be found near the stream mouth in streams that end in terminal waterfalls (Maciolek 1977a; Nishimoto and Kuamoo 1991). They appear to spend much more of their time in mid-water pools than other species (Kinzie and Ford 1982), although they also have a strong affinity for fast riffles (Timbol et al. 1980). 'O'opu alamo'o is known for its remarkable climbing ability and can be found at the highest elevation of any Hawaiian goby.

Lau (1973) found the diet of 'o'opu alamo'o to consist of algae, crustaceans, and insect larvae with the native mountain shrimp ('opae) and algae including Microspora sp. and Bacillariales as the most common food items. Larger gobies ate more animal material while smaller ones ate more algae (Lau, 1973). Mature males are aggressive and show territorial behavior (Lau 1973; Maciolek 1977; Nishimoto and Fitzsimons 1986). Females tend to move freely up and down the stream and around pools, while males are very site specific and defend a discrete territory (Nishimoto and Fitzsimons 1986).

Sicyopterus stimpsoni ('o'opu nopili) is also found in the mid to upper stream reaches, and tends to utilize more rapid stream velocities (Kinzie 1988). Nopili appear to be restricted to relatively undisturbed streams with good water quality and a high rate of discharge (Kinzie 1990). Tomihama (1972) reported that while 'o'opu nopili can climb waterfalls, it is less adept at this than 'o'opu alamo'o. While the two species' distributions can greatly overlap, alamo'o may be found at higher reaches. A tagging study by Kinzie and Ford (1982) showed 'o'opu nopili to be quite sedentary. It is herbivorous, feeding on diatoms and filamentous blue-green algae (Kinzie and Ford 1982; Tomihama 1972).

Awaous guamensis ('o'opu nakea) is the most common Hawaiian freshwater goby and is found in lower and middle stream reaches (Ford and Yuen 1988). This species is found on all the major islands, although on O'ahu the population sizes and the number of streams inhabited are small (Kinzie 1990). A fishery exists for 'o'opu nakea on the Island of Kaua'i, where they are caught in large numbers during their annual spawning run to the stream mouth following heavy fall flooding (Heacock, personal communication).

'O'opu nakea is an omnivore; filamentous algae makes up approximately 84% of the gut volume and animal matter, especially chironomids, the other 16% (Ego 1956; Kido et al. 1993). It has been suggested that nakea probably compete with alamo'o for food, and to some extent space (Timbol et al. 1980). 'O'opu nakea are typically found in deeper slower moving waters (Ego 1956; Kinzie 1988).

Stenogobius hawaiiensis ('o'opu naniha) and Eleotris sandwicensis ('o'opu akupa) typically occur in lower stream reaches and estuaries. 'O'opu naniha is the only Hawaiian goby that does not show strong territorial behavior (Fitzsimons and Nishimoto 1991). It has a planktonic marine larval stage of approximately 135 days (Radtke et al. 1988). Although it possesses fused pelvic fins, 'o'opu naniha is apparently neither a strong swimmer nor climber and occurs mainly along stream margins and other low flow areas near the stream mouth (Fitzsimons and Nishimoto 1991). 'O'opu akupa lacks the fused pelvic fins characteristic of true gobies and thus is found only in stream reaches below the first precipitous waterfall (Fitzsimons and Nishimoto 1991; Kinzie and Ford 1982).

'O'opu naniha is omnivorous and 'o'opu akupa is a predatory carnivore. Gut content analysis of akupa has shown them to prey on small benthic invertebrates, snails, shrimp, insects, and other fish (Kinzie and Ford 1982; Timbol 1972). 'O'opu naniha is absent from both Waikolu and Pelekunu Streams. 'O'opu akupa is present in Pelekunu Stream but rare in Waikolu Stream. Neither species is discussed in this report.

Longitudinal distribution

Hawaiian stream gobies are known to separate out along the gradient from mouth to headwaters (Figure 2). The eleotrid (akupa) and one goby (naniha) are only found in estuaries or below the first waterfall. 'O'opu nakea, the largest goby, tends to be found in lower reaches, especially in streams with precipitous waterfalls. 'O'opu nopili often overlaps with nakea but may be found further upstream as well. 'O'opu alamo'o is found at the highest elevation of all the gobies. The number, and relative gradient, of waterfalls appears to play an important role in the overall distribution of species. In streams with a terminal waterfall 'o'opu alamo'o may be found near the ocean (Nishimoto and Kuamoo 1991) while in streams with relatively low gradient and no major waterfalls 'o'opu nakea can be found far upstream (personal observation).

Study sites

Waikolu Stream

Waikolu Valley lies on Moloka'i's rugged north shore (Figure 3), east of the Kalaupapa Peninsula and within the Kalaupapa National Historical Park which encompasses the Kalaupapa Peninsula, the Waialaia Basin, and Waikolu Basin. Waikolu Valley is approximately 6.4 km (4 mi) long and about 1.6 km (1 mi) wide at the mouth of the valley. The upper valley is narrow with steep valley walls. Waikolu Stream is deeply entrenched in the valley floor, with large boulders deposited in the streambed. Total perennial tributary length is approximately 14 km (9 mi). Its headwaters arise from mountain bogs between Pepeopae and Pu'u Ali'i just above an elevation of 1,219 m (4,000 ft) on the interfluve that separates Waikolu and Pelekunu Valleys.

An extensive water collection system exists in the upper midreach Waikolu Stream. Water diversion through the 8.2 km (5.1 mi) Waikolu Tunnel began in November 1960. Three surface water diversion structures at approximately 304 m (1,000 ft) elevation include two that collect water from tributaries to Waikolu Stream and one on the main stream (referred to in this report as the "upper dam"). There is also a surface water diversion structure (referred to in this report as the "lower dam") at 223 m (730 ft) where water is collected and pumped back up to the tunnel. There are three established wells (two in the valley and one in the tunnel) and three new wells, drilled in 1988, in the floor of Waikolu Valley. Water is transported through the Waikolu tunnel for agricultural purposes on the western and southern portions of Moloka'i.

Since diversions started, the intermediate reaches of Waikolu Stream carry only 50% of natural undiverted flow conditions, while in the lower reaches the percentage increases to 70%, due to intermediate surface runoff and groundwater accretion (Diaz, in prep.). These estimated percentages have dramatic seasonal variations; while the difference in flow volume as an average for the rainy period is 10%, during the dry season that difference reaches 22% (Figure 4). August is the most critical period in terms of water withdrawals because flows are naturally low at this time (Walsh et al. 1992).

Pelekunu Stream

Pelekunu Stream and its seven named tributaries lie in a large valley bounded on the south by Olokui and Wailau Valley and on the north by Pu'u Ali'i and Waikolu Valley. Total tributary length, including unnamed creeks and springs, is over 16 km (10 miles). Pelekunu is one of the last free flowing streams in the state. While it could have been considered as typical of Hawaiian perennial streams, Pelekunu is now one of the few streams that remains relatively unaltered by humans (Hawai'i Stream Assessment 1990).

Water diversions and population structure

Water diversions are one of the most damaging changes to stream systems in Hawai'i (Maciolek 1975). Pelekunu Stream is one of the few streams left in Hawai'i that is relatively pristine (Hawai'i Stream Assessment 1990). A comparison of Pelekunu Stream to nearby Waikolu Stream, which has a number of diversion structures, provides an excellent opportunity to evaluate the impacts of water diversion on community structure. The potential impacts of dewatering are especially important here as there is a possibility that Pelekunu Valley may be developed as a major source of water for the Island of Moloka'i at some time in the future (Ford and Yuen 1988).

Hawaiian gobies are dependent upon free access to the sea to complete their life cycle. The impact of diversions on fauna in oceanic islands such as Hawai'i can be especially severe because dewatering will prevent downstream dispersal of larvae and upstream migration of post-larvae (Timbol and Maciolek 1978). Impacts of dewatering on the gobies may also be less immediately obvious, as in the case of niche shifts or decreases in niche breadth either in habitat use or feeding habits, which may lead to gradual long-term decline of species.

Standardized monitoring protocol

With ever-increasing demands for water in Hawai'i, managers are faced with the need to make decisions balancing water removal for use by humans with maintaining the viability of stream ecosystems. Current information on the occurrence, relative abundance, and instream distribution of 'o'opu in Hawai'i is very limited (Nishimoto and Kuamoo 1991). The need for standardized, comparable data on distribution and abundance of 'o'opu in streams throughout the state is essential (Baker 1991; Honigman and Newman 1991).

At one time electroshocking was the most commonly used method to collect data on 'o'opu populations in Hawaiian streams (Maciolek and Timbol 1980; Nishimoto and Kuamoo 1991). However, electroshocking is difficult and relatively inefficient in most Hawaiian streams (Baker 1991; Nishimoto and Kuamoo 1991). The boulder substrate and benthic behavior of the gobies makes it difficult to retrieve the fish subsequent to shocking. Also the limited access to most reaches makes the use of the electroshocking equipment difficult. Similar considerations apply to the use of seines, except near stream mouths. Consequently, visual surveys conducted using mask and snorkel are typically the most efficient method for determining the distribution and abundance of 'o'opu in Hawaiian streams.

Two types of visual survey methods are currently being used in Hawaiian streams: transects (see Kido et al. 1993) and quadrats (for example Baker 1991; Brasher 1991; Hodges 1994; Kinzie et al. 1990; Nishimoto and Kuamoo 1991; and Smith 1995). The relative efficiency and accuracy of the two methods is currently being evaluated. Some studies show that transects may underestimate 'o'opu densities compared to quadrats, as gobies along the transect may be scared away as the observer moves along the transect, or if gobies are being herded along the transect (Baker 1991; Baker and Foster 1992; Kido et al. 1993).

Quadrats allow observers to efficiently collect information on 'o'opu distribution and abundance over long distances. Strict attention must be paid to ensure random placement of stations within a stream reach and quadrats within a station. In some instances placement of stations should be stratified to include all major habitat types (Baker 1991). For example, in many cases deep pool habitats may be under represented if sampling is not stratified by pool and run/riffle sections (as discussed in Brasher 1996; Hodges 1992; and T. Payne, personal communication).

It is important to differentiate between "haphazard" selection where the observer chooses quadrat locations while in the field, being careful to avoid bias in the selection, and "random" selection where quadrat locations are chosen prior to starting the survey, using a random number table (or other source of random number generation). To have results that are truly comparable between observers, over time, and between streams, random numbers must be used to select quadrat locations. Station location selections may be based on random numbers, as in this study, or may be modified if limited time or access prevents the entire stream from mouth to headwaters from being included in the survey.

Although developed independently for Hawaiian streams (see Baker and Foster 1992; Brasher 1991; and Kinzie et al. 1990 for earlier surveys), quadrat counting methods in this study are nearly identical to those described by Baker (1991) and Baker and Foster (1992). Exceptions are that the methods presented here allow much less room for "decisions" by the observer. Specifically, the size of the quadrat is always one square meter and the time spent recording data in each quadrat is always three minutes. While my earlier quadrat surveys (Brasher 1991; Kinzie et al. 1990) allowed more flexibility, the methodology presented here is much more stringent to increase consistency between observers, making comparisons between streams or over time more reliable.

METHODS

Station locations

Permanent monitoring stations were established at randomly chosen locations from the mouth to the headwaters of each stream. Twenty-three stations were selected in Waikolu Stream (Figure 5) and twenty stations in Pelekunu Stream (Figure 6). The number of stations chosen was intended to provide adequate coverage along the entire stream length and at the same time have a survey that could be completed within 4-5 days. Preliminary analyses were also conducted to determine a sample size adequate to statistically evaluate changes in population density.

Using a sampling area of three hundred square meters at each station, ten one meter square quadrats were randomly selected using a Cartesian coordinate system (Appendix B). One purpose of the large sampling area was to reduce the disturbance to other quadrats while one quadrat was being counted. Because quadrat locations were determined randomly, some quadrats at some stations were very close to each other, even adjacent. Monitoring stations were simultaneously established for Waikolu and Pelekunu Streams on Moloka'i and Oheo Gulch, Kipahulu District of Haleakala National Park, as part of a plan to establish permanent monitoring protocol for the National Park streams (see Hodges 1994 for details of the Oheo Gulch studies).

Monitoring protocol

A survey technique utilizing quadrats was selected as the most effective method to quantify species composition and abundance along the longitudinal gradient from the mouth to the headwaters in Waikolu and Pelekunu Streams. Surveys were conducted quarterly over a two-year period to provide substantial baseline data to which future monitoring surveys can be compared, and to determine natural variation in 'o'opu distribution and density over time.

Survey design

The 'o'opu monitoring surveys were designed to establish standardized methods for monitoring streams in Hawai'i. Thorough, quantitative data on 'o'opu distribution and abundance, collected in a rigorous scientific manner is necessary for sound management decisions. The initial surveys were conducted quarterly (four times per year) to determine natural fluctuations in density and distribution. Stations were randomly placed from the mouth to the headwaters to quantify the longitudinal distribution of 'o'opu species and to insure a thorough assessment of the distribution and abundance of the different species of 'o'opu. The surveys established baseline population data for Waikolu Stream and Pelekunu Stream that can be compared to future monitoring surveys in these streams and to other streams throughout the state. Finally, analysis of information collected during monitoring surveys is one of the tools for evaluating impacts of water diversions on stream ecosystems in Hawai'i, and this study describes possible ways this can be done.

Species identification

Since the purpose of designing standardized 'o'opu monitoring protocol for the Hawaiian streams is the collection of reliable and accurate data for comparison between streams and within a stream over time, the importance of training and rigorous adherence to methodology guidelines must be emphasized. Trained observers have been shown to be highly reliable in their observations, while relatively untrained observers are much less consistent (Baker 1991; Hodges 1994; Kido et al. 1993).

To count the 'o'opu, each observer unobtrusively paced off the distance to the appropriate quadrat location based on the coordinate system. Always approaching from downstream, the observer carefully and quietly lowered herself or himself into the water and moved slowly toward the quadrat location. A one meter long thin metal wire was used to determine the exact boundaries of the quadrat. Typically an observer would place the wire along the left edge of the quadrat, then along the downstream edge, noting the location of the boundaries of the quadrat. With the wire then lying along the left edge of the quadrat, the observer recorded all 'o'opu within the quadrat during a three-minute period, noting species and size class (in half-inch increments) of all 'o'opu observed. In the rare instances when a newly recruited 'o'opu was too small to identify to species it was recorded simply as "hinana" (post-larval goby).

RESULTS

Distribution and abundance

For this analysis, the streams were divided into four sections: mouth, lower, mid and upper reaches, to allow for clearer description of the longitudinal distribution of the 'o'opu. (Actual stations assigned to each section are listed in Appendix C).

Overall densities (gobies per square meter) of 'o'opu nakea were much lower in Waikolu Stream (Figure 7) than in Pelekunu Stream (Figure 8), except at the stations closest to the mouth where densities appear similar. However, three of the sampling periods are missing in Pelekunu Stream for the stations closest to the mouth, so the results are inconclusive until additional surveys are completed. In the lower, mid and upper reaches, 'o'opu nakea were substantially more abundant in Pelekunu Stream than in Waikolu Stream. No nakea were observed in the upper stations of Waikolu Stream, above the diverted section.

'O'opu nakea tends to be most abundant closest to the stream mouth. This pattern is most obvious in streams with steep waterfalls that appear to restrict 'o'opu nakea to lower reaches. In streams such as Waikolu and Pelekunu, where the gradient is relatively low, and there are no large waterfalls, 'o'opu nakea may move quite far upstream.

'O'opu nakea were present at all elevations in Pelekunu Stream, and they were much more abundant than at comparable stations in Waikolu Stream. No nakea were observed in the upper reaches of Waikolu Stream, where the two dams and the reduction of flow in the section may have restricted upstream movement.

The greater abundance of 'o'opu nopili at stations near the mouth in Waikolu Stream is due in part to the large number of new recruits to that area. However, over time the abundance of recruits did not translate into higher densities of adult nopili upstream, and in fact, at all other stations at comparable elevations, 'o'opu nopili are slightly more abundant in Pelekunu Stream than in Waikolu Stream.

'O'opu alamo'o typically increase in abundance with increasing distance upstream, and can be found the farthest upstream of any of the native gobies. Interestingly, 'o'opu alamo'o were more abundant in the lower reaches of Waikolu Stream, and less abundant in the higher reaches, especially above the diverted section (Figure 13). In Pelekunu Stream, 'o'opu alamo'o showed the expected pattern, with highest densities at the highest elevation (Figure 14). Again, because stations at the mouth of Pelekunu Stream were only sampled five times, it is difficult to draw conclusions about this section until additional data is collected. At stations in the upper stream sections, densities of 'o'opu alamo'o were two to three times higher in Pelekunu Stream than in Waikolu Stream.

The pattern observed in Pelekunu Stream of increasing abundance of 'o'opu alamo'o with increasing distance upstream is the expected pattern for Hawaiian streams. The lower number of 'o'opu alamo'o in the mid and upper reaches of Waikolu Stream may be a result of the decreased flow and periodic dewatering of the stream section below the upper dam, reducing available habitat for the 'o'opu and inhibiting upstream migration.

Size distribution

The size of each 'o'opu observed was estimated to the nearest half inch (standard length). 'O'opu nakea are the largest of the 'o'opu, some reaching greater than 9.5 inches standard length (S.L.) in Waikolu and Pelekunu Streams. In Pelekunu Stream, during all sampling periods and at all stations combined, over 40% of 'o'opu nakea were juveniles (< 2 inches S.L.). In Waikolu Stream, on the other hand, adult nakea (3.5 - 5 inches were most common).

Size distribution of 'o'opu nopili and 'o'opu alamo'o was similar in Waikolu Stream and Pelekunu Stream. More than half of all 'o'opu nopili observed in both streams were young adults (1 to 2.5 inches standard length). More than half of all 'o'opu alamo'o in Waikolu Stream, and two thirds in Pelekunu Stream were young adults (1 to 2 inches standard length).

Size classes along the longitudinal gradient

Very few 'o'opu nakea were observed in sections of Waikolu Stream other than near the mouth, and none were observed in the uppermost section (Figure 17). The wells and diversion structures in Waikolu Stream may have reduced the amount of suitable habitat available for 'o'opu nakea in the lower and mid reaches of the stream by reducing discharge. Additionally the two dams and the periodically dry area between them appear to form a barrier to upstream movement by 'o'opu nakea in Waikolu Stream. All sizes of 'o'opu nakea, ranging from less than 0.5 inches to greater than 9 inches, were present at the stations near the mouth of Waikolu Stream. The distribution of size classes for 'o'opu nakea in Waikolu Stream approximated a normal curve, with a mean size of 4 to 4.5 inches S.L.

'O'opu nakea were present in all four sections of Pelekunu Stream and most abundant in the lower section (Figure 18). Although the estuary typically contains the largest 'o'opu nakea (up to 12 inches or more) this was not the case in Pelekunu Stream. While the mouth of Pelekunu Stream is estuary-like, the flow spreads out among several channels, that are often shifting and usually quite shallow (< 0.5 m). The largest 'o'opu nakea are typically found in deep pools (> 1 m), a habitat not well represented at the mouth of either of these two streams. Nakea were very uncommon in Waikolu Stream, especially in the upper reaches. Waikolu Stream has no real estuary, and the mouth consists of a relatively shallow boulder riffle, again not ideal habitat for large 'o'opu nakea. Large 'o'opu nakea have been observed in both Waikolu and Pelekunu Streams, but are relatively rare so may be under-reported by the survey techniques.

The lower and mid sections of Pelekunu Stream had large numbers of young adult 'o'opu nakea (1 to 3 inches S.L.), while the upper section had the largest (and presumably the oldest) 'o'opu nakea. Because Pelekunu Stream lacks the steep waterfalls that prevent further upstream movement by 'o'opu nakea in many other streams, nakea are relatively abundant in even the upper reaches of Pelekunu Stream. The habitat at the three stations representing the upper stream section included several deep (> 1 m) pools--suitable for large 'o'opu nakea. Compared to the lower and mid reaches, there were relatively few small nakea (< 2.5 inches) at stations in the upper reaches.

'O'opu nopili show nearly identical distributions of size classes in Waikolu Stream (Figure 19) and Pelekunu Stream (Figure 20). 'O'opu nopili were most abundant at stations near the mouth, especially the first two size classes (0.5 to 1.0, and 1.0 to 1.5 inches S.L.), representing new recruits and small gobies likely still migrating upstream. Very few newly recruited (0.5 to 1.0 inches S.L.) 'o'opu nopili were observed above the section of stream near the mouth. Large (4.0 to 6.0 inches S.L.) adult nopili were observed at all stations, except in the mid and upper sections of Waikolu Stream. This is difficult to see in Figures 19 and 20 because the smaller 'o'opu nopili were so abundant (mean of 150 to 250 per station) while larger 'o'opu nopili were less common (mean less than 10 per station). Also, larger gobies take up more room and are more territorial, so fewer will be present in each meter square quadrat.

'O'opu alamo'o are the smallest of the three goby species, with adults typically reaching 2.0 to 3.0 inches S.L., although 'o'opu alamo'o up to 4.5 inches were observed in both streams (Figure 21 and Figure 22). 'O'opu alamo'o in the size class 1.0 to 1.5 inches S.L. were the most abundant size in all sections of both Waikolu Stream and Pelekunu Stream. Distribution and abundance of size classes was similar in both streams, although more 'o'opu alamo'o were present in the mouth and lower sections of Waikolu Stream and in the upper section of Pelekunu Stream. New recruits (0.5 to 1.0 inches S.L.) were uncommon in the upper reaches, presumably by the time the 'o'opu have migrated this far they have grown into the next size class.

Seasonal changes in abundance

For efficiency in long-term monitoring or between-stream comparisons, it may be desirable to look at data collected from a number of sites at various elevations and then grouped together. For example, by grouping stations, two streams with different numbers of stations could be compared. Also, initial baseline surveys may include more, or less, number of stations than future monitoring surveys in subsequent years.

Abundance of all three species of 'o'opu, in both Waikolu Stream and Pelekunu Stream remained consistent between seasons and over the two-year monitoring period. With data for all stations combined, the mean number of 'o'opu per station varied the least for 'o'opu nakea (Figure 23) and the most for 'o'opu nopili (Figure 24), with fluctuations in 'o'opu alamo'o density falling between the two (Figure 25). The large number of post-larval 'o'opu nopili returning to the streams in May 1993 contributed significantly to the variation in mean number of nopili observed.

Recruitment

Recruitment (return of post-larval 'o'opu from the ocean to the stream) was determined by the number of 'o'opu less than one inch observed at each station. For the most part, post-larval gobies (hinana) were identified to species. In a few instances when the observer could not determine the species of a newly recruited 'o'opu it was recorded simply as "hinana." Only those hinana that could be identified to species are discussed here. The stations closest to the mouth in Pelekunu Stream, where newly recruited 'o'opu would be expected to be most abundant, were only surveyed five of the eight possible times during this study. Therefore, recruitment events in Pelekunu Stream may be underestimated during the months of February and November 1993 and February 1994 when stations near the mouth were not surveyed.

All 'o'opu less than 1 inch standard length were considered "recruits" for this analysis. These small fish tend to be found in large aggregations, often in the process of migrating upstream. Recruitment appears to occur, at least at some low level, throughout the year. Very few 'o'opu nakea recruits were recorded during the two year monitoring study (Figure 26), although large numbers of post-larval 'o'opu nakea were present near the mouth of Pelekunu Stream in August 1992 and spawned-out nakea and eggs were found at the mouth of Waikolu Stream in November 1992 (personal observations).

The biggest recruitment event recorded during this study occurred in May 1993, when thousands of 'o'opu nopili post-larvae were observed returning to Waikolu Stream (Figure 27). Large numbers of newly recruited 'o'opu nopili were also recorded in Pelekunu Stream at this time and during August 1993. The largest numbers of post-larval 'o'opu alamo'o were recorded in August 1993 and November 1994 in both Waikolu and Pelekunu Streams (Figure 28). Relatively large numbers of 'o'opu alamo'o recruits were also observed in Waikolu Stream in May 1993 and 1994 and February 1994, and in Pelekunu Stream in November 1993 and February 1994.

While data from this monitoring study do not provide information on exact timing or abundance of post-larval goby recruitment events, they do indicate levels of recruitment and variation over time, that can be compared with levels obtained during future monitoring surveys of these streams or other streams where similar, or the same, methods are used.

Impacts of water diversion on distribution and abundance

In Waikolu Stream, potential impacts of the water diversions on native stream gobies and possible consequences of either a restoration of flow or further depletion in the future can be analyzed using data collected during the baseline monitoring surveys. To examine the impact of the current water diversion regime, species composition and density at stations along the elevational gradient was analyzed. Because Waikolu and Pelekunu Streams are located in adjacent valleys and have similar geomorphologic, watershed and rainfall characteristics, as well as historical human impact, species distribution and abundance can be expected to be similar. A major physical difference between Waikolu and Pelekunu Streams is that there are a number of diversion structures and wells in the upper-mid reach of Waikolu Stream which reduce flow and at times dewater the stream in some sections, while no water removal activities occur on Pelekunu Stream. By looking at stations of comparable elevation and distance from the mouth, 'o'opu distribution and abundance in Waikolu and Pelekunu Streams can be compared.

Overall, 'o'opu nakea densities (gobies per square meter) were much lower in Waikolu Stream than in Pelekunu Stream (Figure 29). 'O'opu nakea densities were highly variable between stations in Pelekunu Stream while the densities in Waikolu Stream were consistently low and showed little variation. The mean number of 'o'opu nakea observed at stations closest to the mouth was similar in Waikolu and Pelekunu Streams. For stations in and above the diverted section in Waikolu Stream, 'o'opu nakea densities were substantially less than those at comparable stations in Pelekunu Stream.

'O'opu nopili showed high variation both within and between stations (longitudinally and over time) in Waikolu Stream and high variation between, but not within, stations in Pelekunu Stream (Figure 30). Even excluding the two stations at the mouth of Waikolu Stream where the high variation is a reflection of recruitment events, 'o'opu nopili densities fluctuated greatly in Waikolu Stream. Excluding newly recruited 'o'opu, the mean number of 'o'opu nopili was similar at comparable stations in Waikolu Stream and Pelekunu Stream, except in and above the dewatered section of Waikolu Stream. 'O'opu nopili densities were significantly lower in this section of Waikolu Stream than at comparable stations in Pelekunu Stream.

Mean densities (fish per square meter) of 'o'opu alamo'o were slightly higher in Waikolu Stream than in Pelekunu Stream, up to the diverted section (Figure 31). From the lower dam to the periodically dewatered section in Waikolu Stream, the mean number of 'o'opu alamo'o was higher in Waikolu Stream than in Pelekunu Stream, however variation in Waikolu Stream was extremely large. One possible explanation for the high variation in 'o'opu alamo'o densities at these stations in Waikolu Stream may be that gobies are moving in and out of the section which is occasionally dry, and into these stations which maintain continuous flow due to a tributary that flows into the stream in this area.

In the periodically dewatered section and upstream, significantly fewer 'o'opu alamo'o were observed at stations in Waikolu Stream than at comparable stations in Pelekunu Stream. Even at stations above the upper dam in Waikolu Stream, alamo'o densities were much lower than at corresponding stations in Pelekunu Stream, presumably because of the difficulty of moving through the dewatered sections and the surface water diversions at the upper dam.

CONCLUSIONS

Summary

With ever-increasing demands for water in Hawai'i, managers are faced with the need to balance water removal for use by humans with maintaining the viability of stream ecosystems. Thorough, quantitative data on 'o'opu distribution and abundance, collected in a rigorous scientific manner is necessary for sound management decisions. This study was designed to establish standardized methods for conducting surveys of native 'o'opu populations to monitor streams in Hawai'i. These methods may be used for long-term comprehensive monitoring projects as described here, or for one-day reconnaissance surveys to evaluate stream conditions, perhaps as a preliminary step in planning more extensive monitoring surveys or ecological studies.

To collect baseline data on Waikolu Stream and Pelekunu Stream, a two-year study with quarterly 'o'opu surveys at randomly selected stations located from the mouth to the headwaters of each stream was conducted. This study focused on three species of 'o'opu: 'o'opu nakea, 'o'opu nopili and 'o'opu alamo'o. Abundance of each species and size of each goby was recorded at each sampling station. Results of these surveys provide information on natural variation in 'o'opu distribution and density over time, and can be compared with future monitoring surveys in these streams or to data collected in other streams across the state.

Overall densities of 'o'opu nakea were much lower in Waikolu Stream than in Pelekunu Stream and no 'o'opu nakea were observed in the upper stations of Waikolu Stream, where the two dams and the reduction of flow in this section may have restricted upstream movement. 'O'opu nakea were observed at all elevations surveyed in Pelekunu Stream, suggesting that in streams where the gradient is relatively low, and there are no large waterfalls, 'o'opu nakea may move quite far upstream.

In both Waikolu and Pelekunu Streams, densities of 'o'opu nopili were highest near the mouth, decreasing with upstream distance. While 'o'opu nopili are more abundant at stations near the mouth in Waikolu Stream than in Pelekunu Stream, at all other comparable stations, nopili are more abundant in Pelekunu Stream. The greater abundance of 'o'opu nopili at stations near the mouth in Waikolu Stream is due in part to the large number of hinana (post-larval gobies returning to the stream from the ocean) in that area. However, over time the abundance of hinana in Waikolu Stream did not translate into higher densities of adult 'o'opu nopili upstream.

In Pelekunu Stream, 'o'opu alamo'o were most abundant at stations at higher elevations. This is the pattern typically observed in Hawaiian streams. However, 'o'opu alamo'o were more abundant in the lower reaches of Waikolu Stream, and less abundant in the upper reaches, especially above the diverted section. The lower number of 'o'opu alamo'o in the mid and upper reaches of Waikolu Stream was most likely a result of decreased flow and periodic dewatering of the stream section below the upper dam, reducing available habitat for the 'o'opu and inhibiting upstream migrations.

Abundance of all three species of 'o'opu, in both Waikolu and Pelekunu Streams, remained consistent between seasons and over the two-year monitoring period. The three species showed considerably more overlap in longitudinal distribution than has previously been reported for Hawaiian streams. This may be due to the relatively low gradient of the stream channel and lack of major waterfalls in the lower and mid reaches, allowing all three species to continue upstream migration, and eliminating the upper reaches as a refuge for 'o'opu alamo'o.

Recruitment appears to occur, at least at some low level, throughout the year. Very few 'o'opu nakea recruits were recorded during the two-year monitoring period although large numbers of post-larval 'o'opu nakea were present near the mouth of Pelekunu Stream in August 1992, and spawned-out nakea and eggs were found at the mouth of Waikolu Stream in November 1992 (both prior to the commencement of the monitoring study).

Future research

This study provides information on longitudinal distribution and abundance of native 'o'opu species in Waikolu Stream and Pelekunu Stream on the Island of Moloka'i. Of immediate interest is how distribution and abundance of 'o'opu varies between streams and between islands. Studies conducted following the methods described here will provide reliable comparisons between streams, creating a much needed data base assessing stream conditions throughout Hawai'i.

Additionally, these surveys indicated probable impacts of diversion structures and water removal on the native species. As decisions are made about water allocation, some streams will have natural flow returned while others will have increased levels of water removal. These situations provide an ideal opportunity to study the impacts of different flow regimes on population structure and the distribution and abundance of native 'o'opu, and should not be wasted.

Studies specifically focusing on critical life stages of 'o'opu, especially reproduction and recruitment, are needed. In order to better manage Hawaiian stream systems, information on cues, timing, and limiting factors for reproduction and recruitment; and how they might vary between streams and between islands, is required.

Lastly, ecosystem level studies, examining interactions between different parts of the food web, and how physical and chemical factors may influence these biological interactions, are needed for Hawaiian streams.

Management recommendations

First, it is recommended that the 'o'opu monitoring program for Waikolu Stream and Pelekunu Stream be continued. At the completion of this study, National Park Service and The Nature Conservancy of Hawaii staff were trained in the monitoring methods. The baseline data collected during this study can be compared with future monitoring surveys to evaluate the impacts of changes in the stream systems (such as an alteration of the current flow regime). An adequate long-term monitoring program for 'o'opu would require a yearly survey. A period of one week would be required for a trained team of observers to conduct an 'o'opu survey in each stream. To ensure reliable results, it is important that the observers be well trained in both species identification and the survey methods.

Because of the logistical difficulties of accessing Pelekunu Stream (helicopter costs may be prohibitive, preventing a second trip to the valley when it is not possible to complete the survey due to flooding), for the purposes of long-term monitoring, some upper stations (Kapuhi 274 and Kawailena 196) should be replaced with additional stations requiring shorter hikes. Eight new stations could be added to provide more thorough coverage, even in the event of one day of flooding during the survey when 'o'opu can not be counted.

Second, in the event of a major change in the stream system (such as a large increase in the amount of water being diverted from the stream, a return of continuous flow to an area that is now often dry, or the addition or removal of barriers to downstream dispersal and upstream migration), more frequent monitoring surveys would be required, and the addition of new survey stations in the vicinity of the alteration may be necessary.

Lastly, a continuous flow from the headwaters to the mouth of the stream allows native species such as 'o'opu to disperse to the ocean as larvae and to migrate back upstream as post-larvae to eventually reproduce and complete their life cycle. Densities of 'o'opu are substantially lower in, and upstream of, the diverted sections of Waikolu Stream compared to the lower reaches of Waikolu Stream and to stations of comparable elevation and distance form the mouth in Pelekunu Stream. A continuous flow of water periodically dewatered sections of Waikolu Stream would improve goby habitat and enhance both downstream dispersal and upstream migration by 'o'opu.

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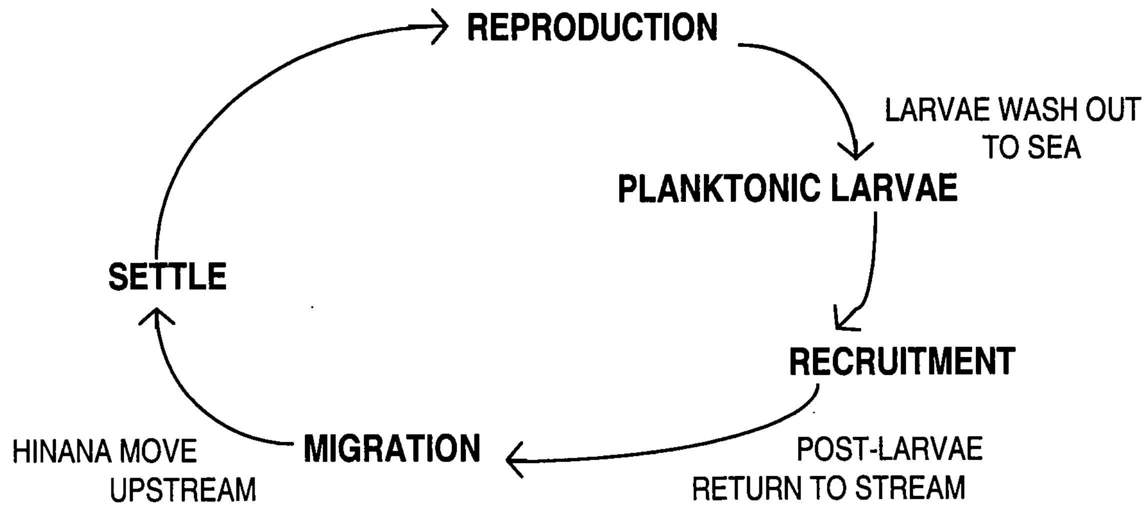


Figure 1. Amphidromous life cycle of Hawaiian Stream gobies (`o`opu).

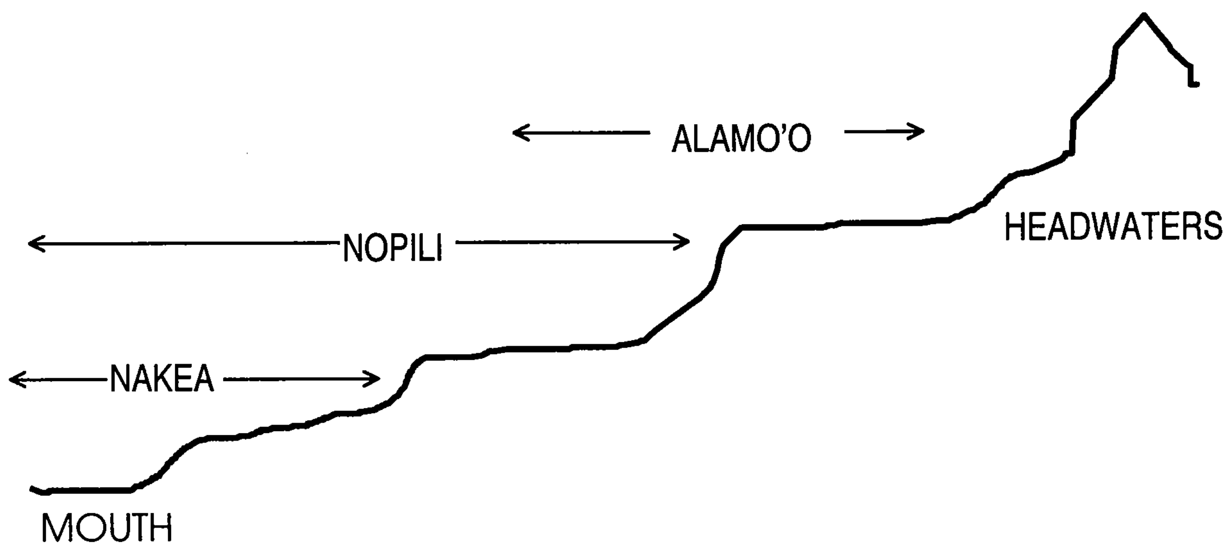


Figure 2. General longitudinal distribution pattern of native stream gobies.

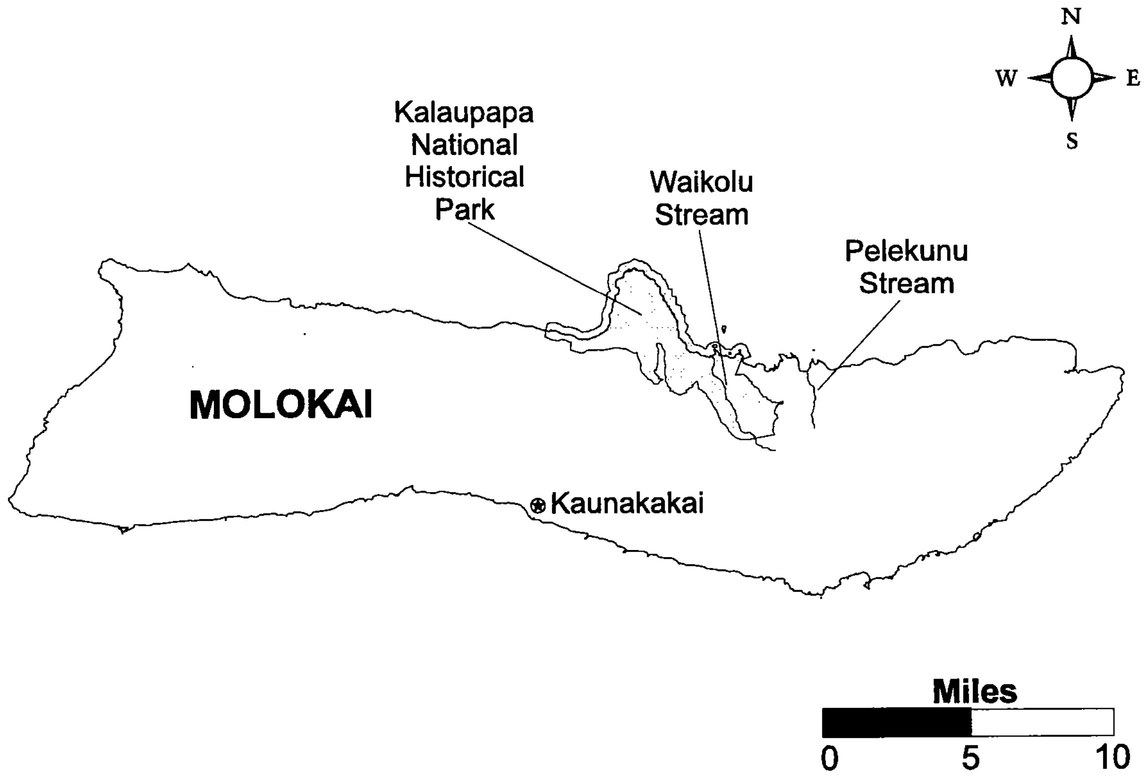


Figure 3. Location of Waikolu Stream and Pelekunu Stream on the Island of Moloka'i

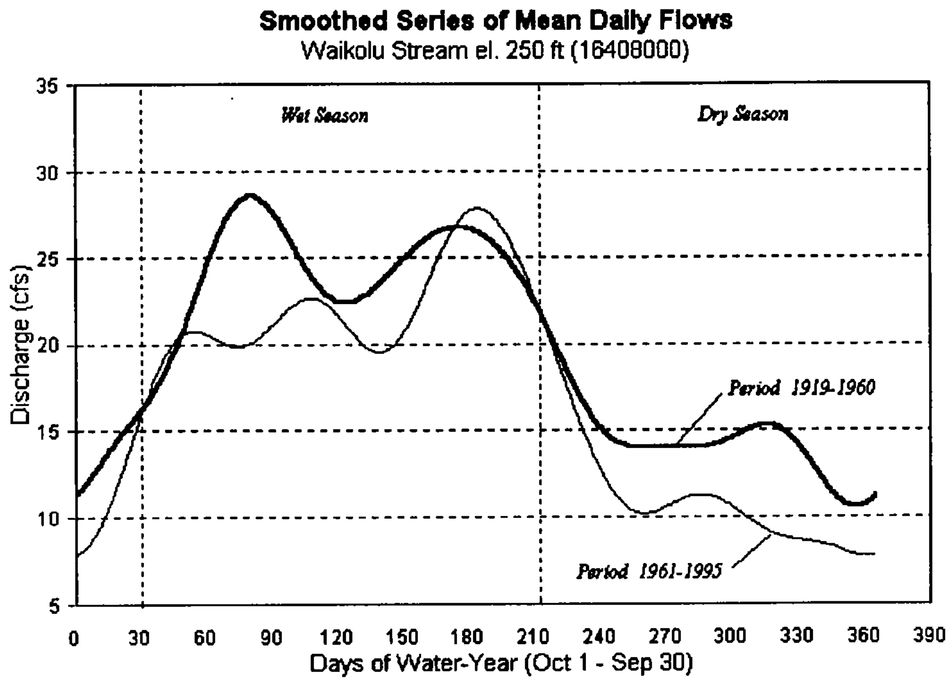


Figure 4. Impact of water diversions on flow volume in Waikolu Stream. Seasonal variation of mean daily flows comparing pre- and post-tunnel periods (from Diaz, in prep.). Mean daily flows from 1921 - 1995 at the "lower" USGS stream gage, located below the diversions.

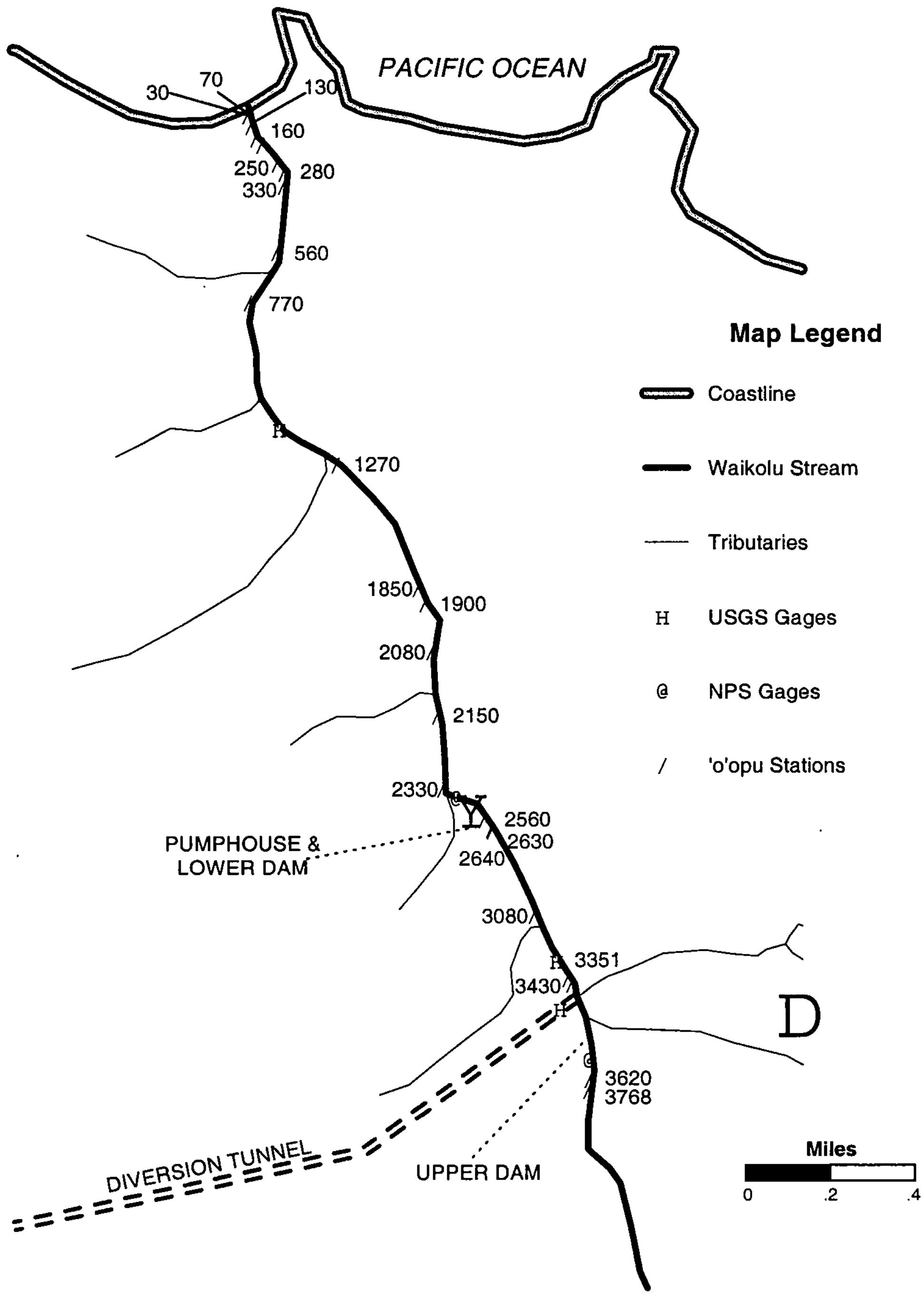


Figure 5. Location of `o`opu monitoring stations in Waikolu Stream.

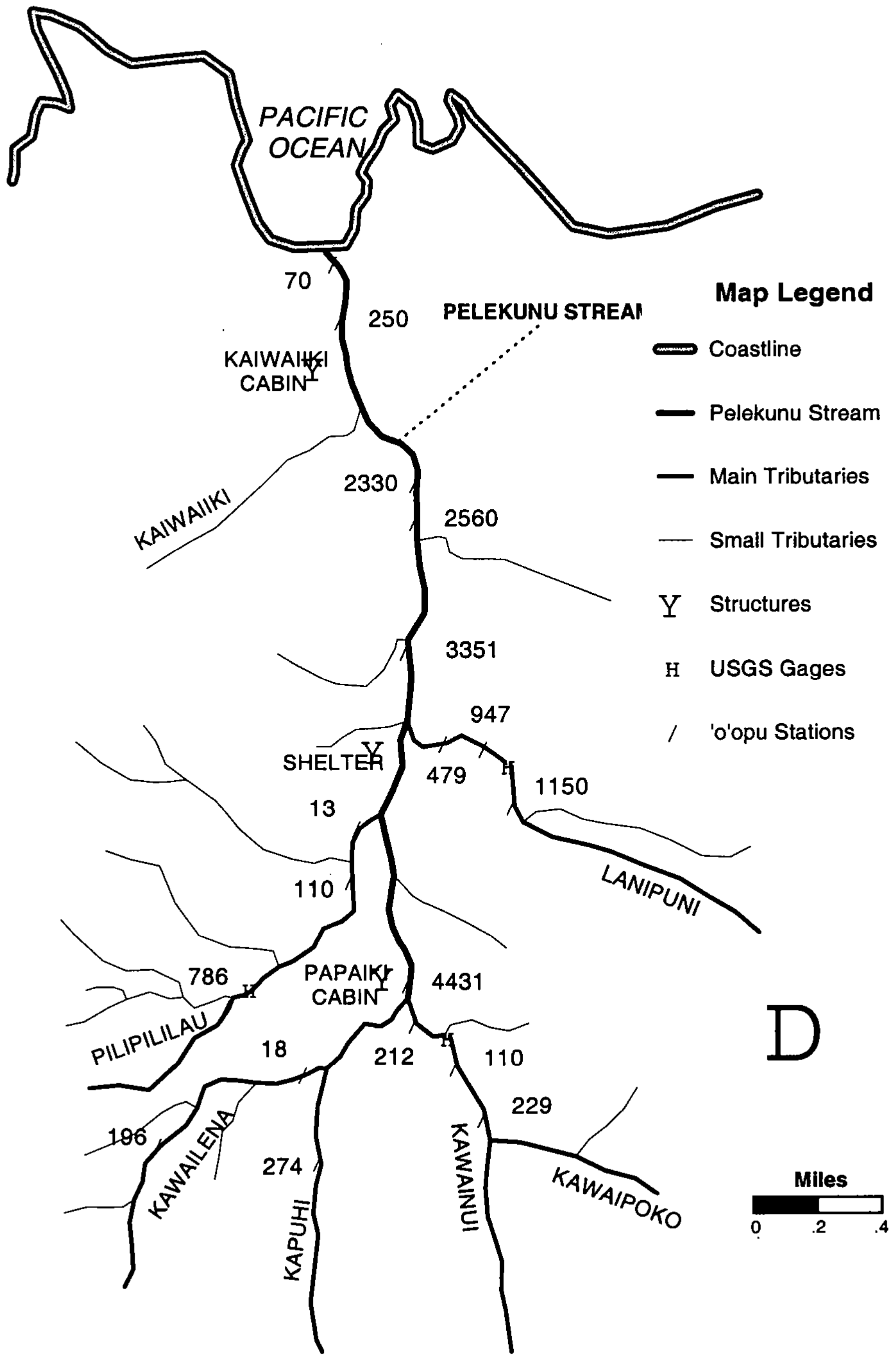


Figure 6. Location of ʻoʻopu monitoring stations in Pelekunu Stream.

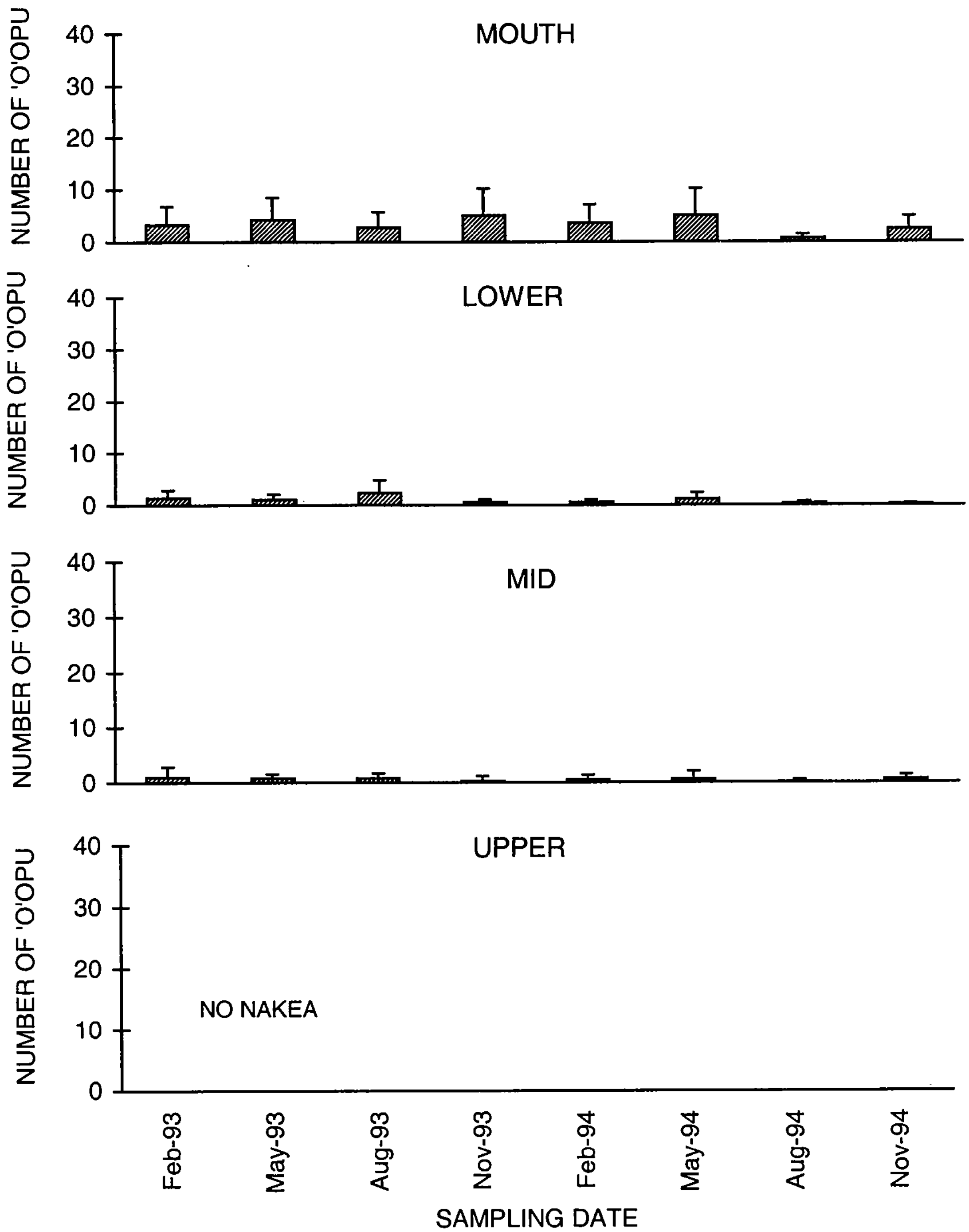


Figure 7. Distribution and abundance of 'o'opu nakea in Waikolu Stream during the two year monitoring period. Stations are grouped into four sections: mouth, lower, mid and upper stream reaches. Error bars equal one standard deviation.

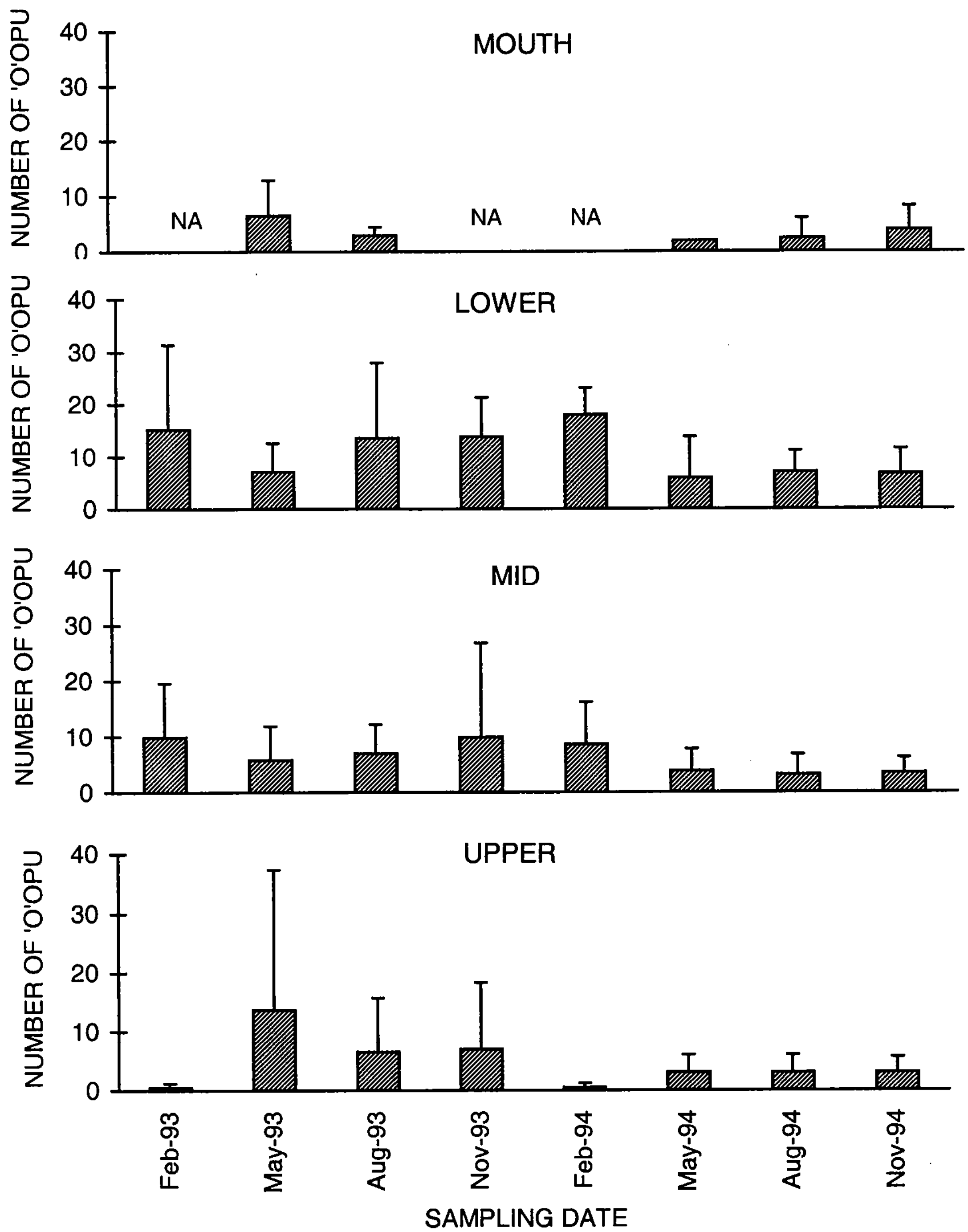


Figure 8. Distribution and abundance of ʻoʻopu nakea in Pelekunu Stream during the two year monitoring period. Stations are grouped into four sections: mouth, lower, mid and upper stream reaches. Error bars equal one standard deviation.

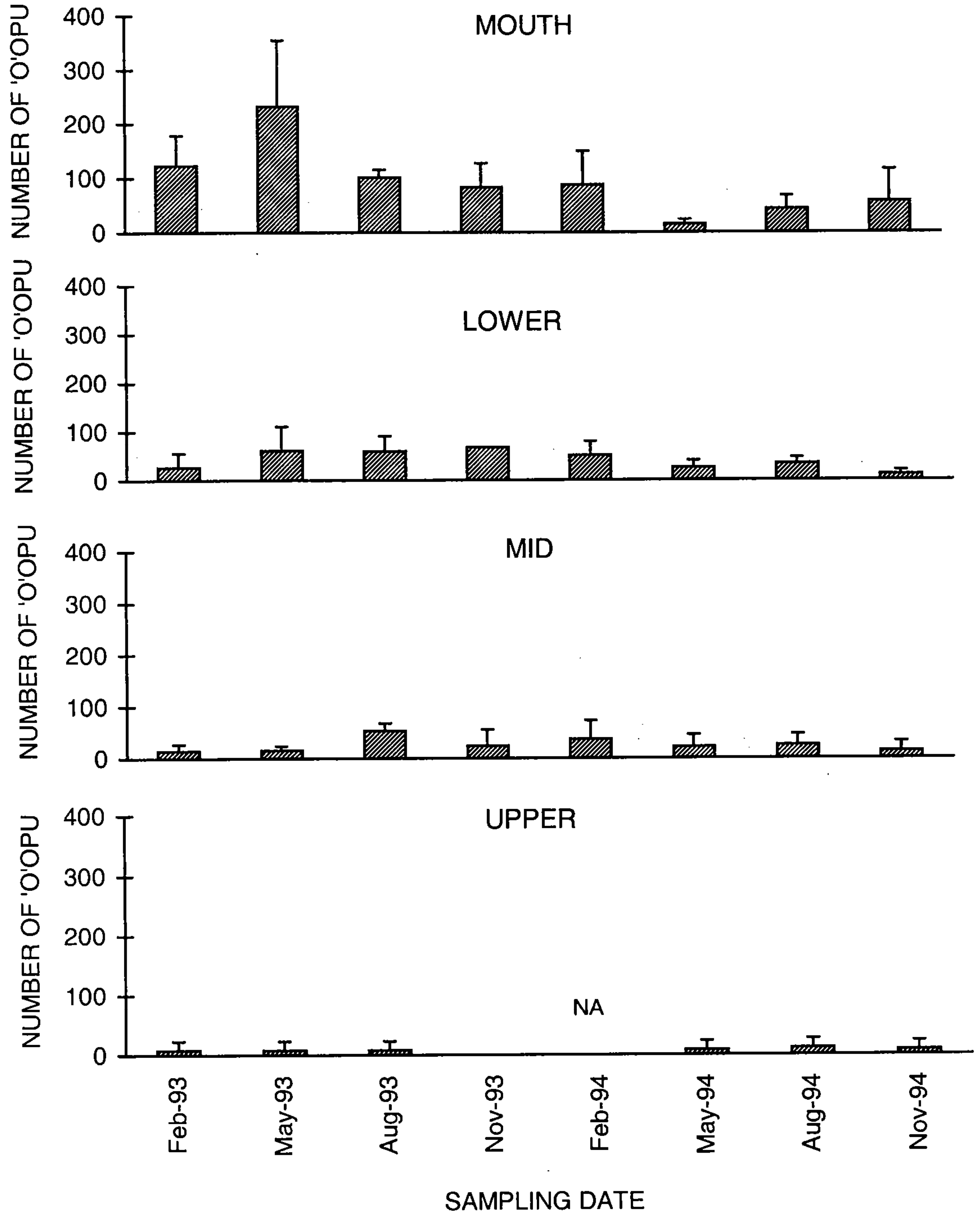


Figure 9. Distribution and abundance of 'o'opu nopili in Waikolu Stream during the two year monitoring period. Stations are grouped into four sections: mouth, lower, mid and upper stream reaches. Error bars equal one standard deviation.

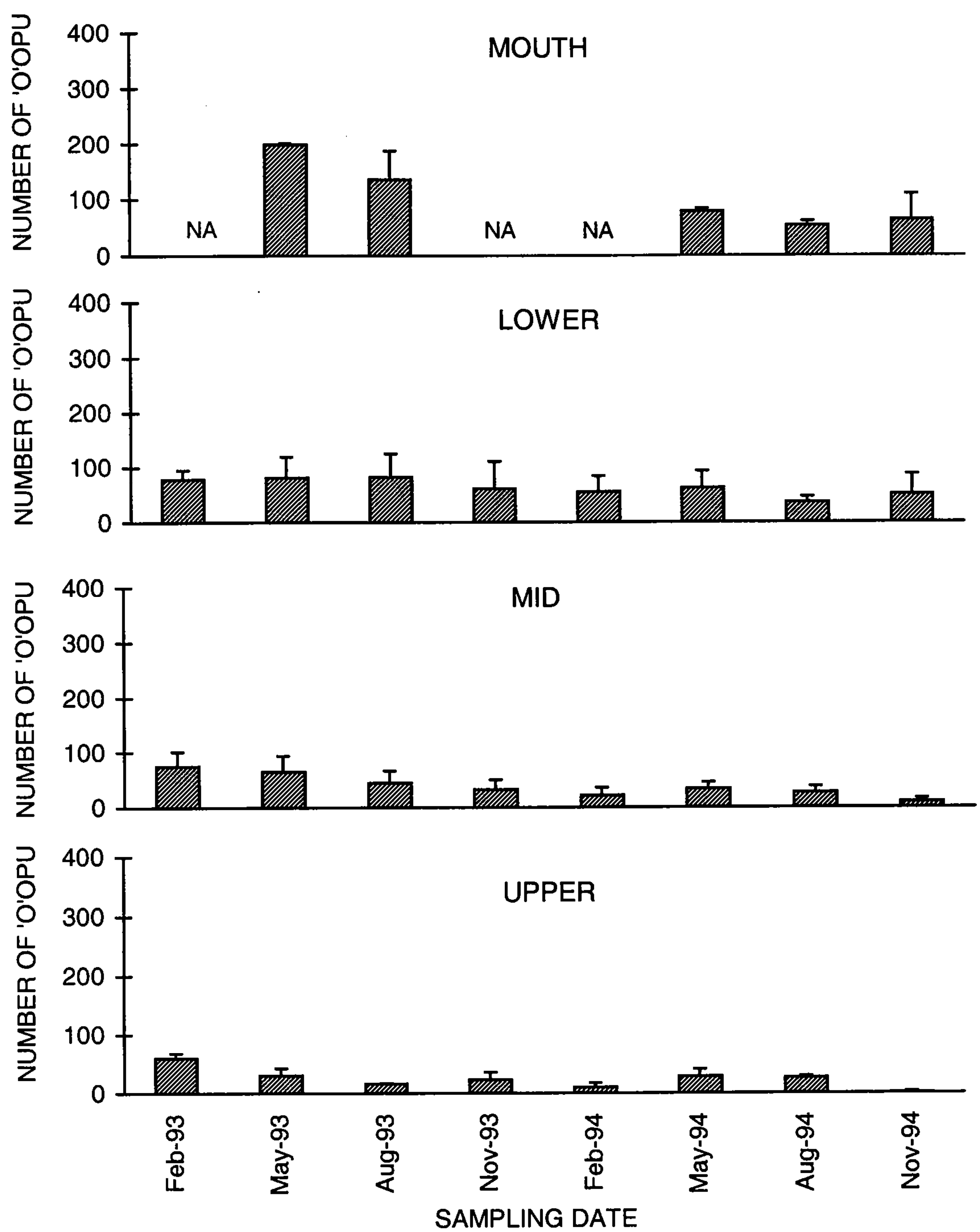


Figure 10. Distribution and abundance of ʻoʻopu nopili in Pelekunu Stream during the two year monitoring period. Stations are grouped into four sections: mouth, lower, mid and upper stream reaches. Error bars equal one standard deviation.

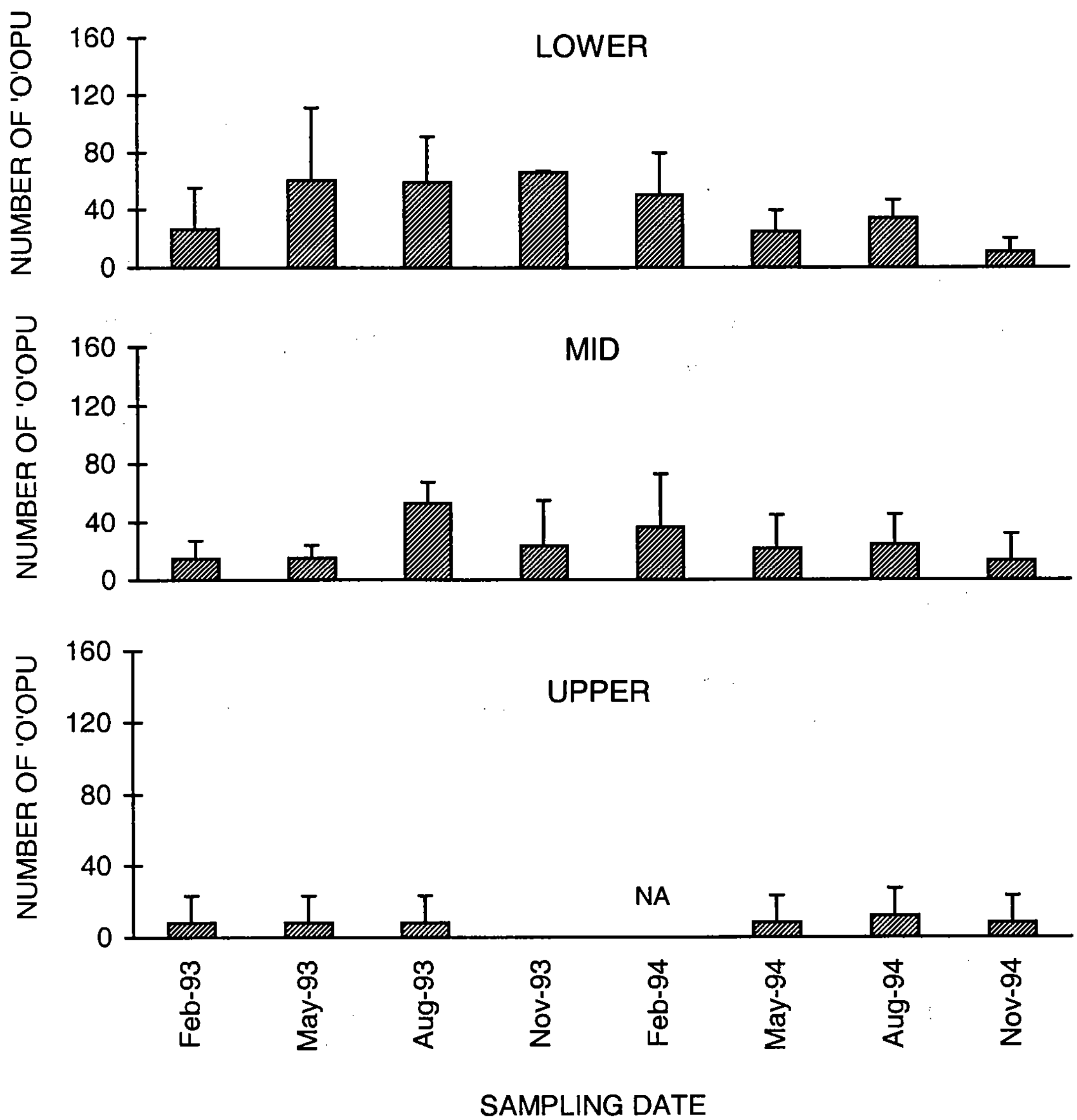


Figure 11. Distribution and abundance of ʻoʻopu nopili in Waikolu Stream during the two year monitoring period. Stream section closest to the mouth omitted. Error bars equal one standard deviation.

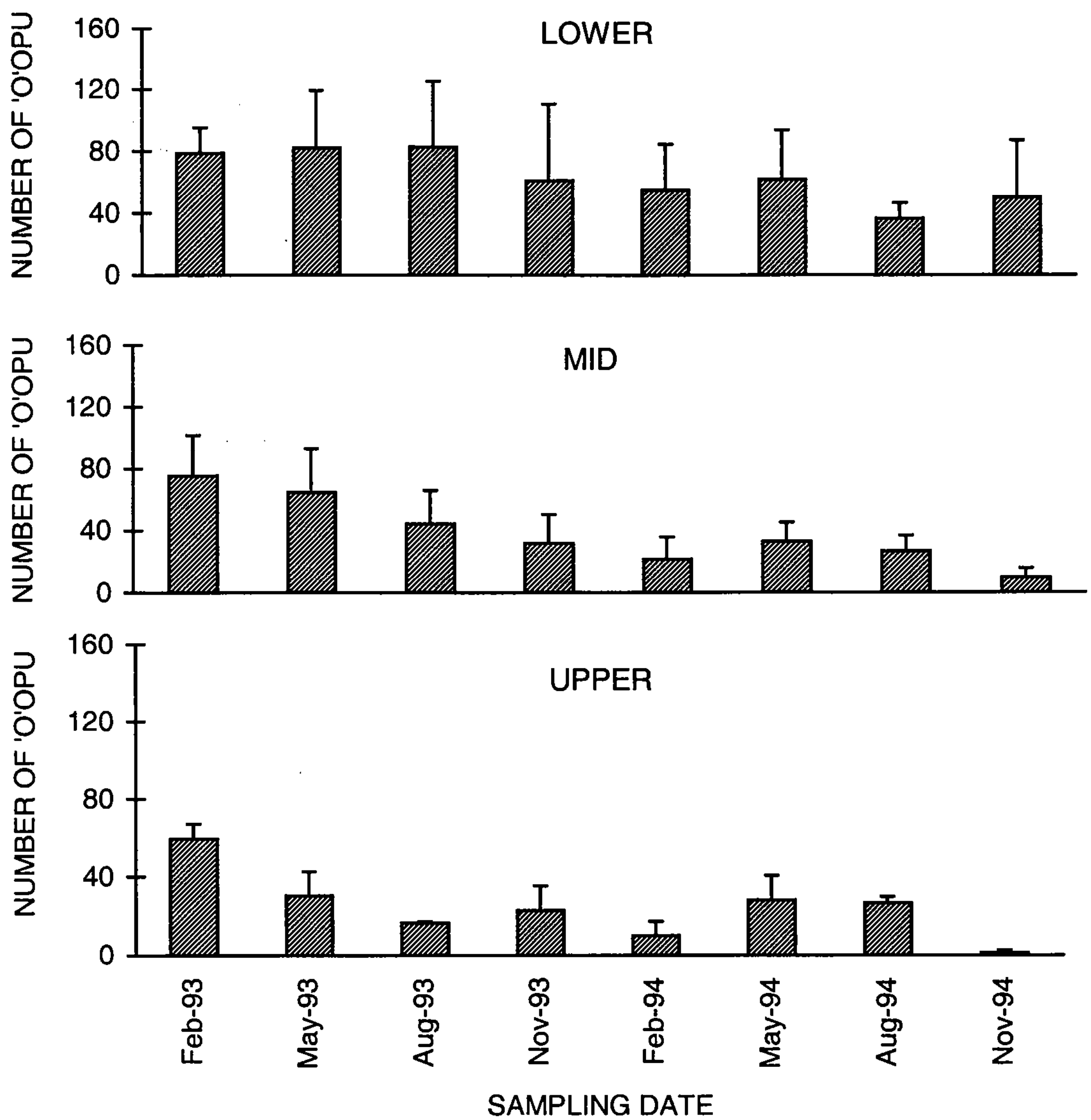


Figure 12. Distribution and abundance of 'o'opu nopili in Pelekunu Stream during the two year monitoring period. Stream section closest to the mouth omitted. Error bars equal one standard deviation.

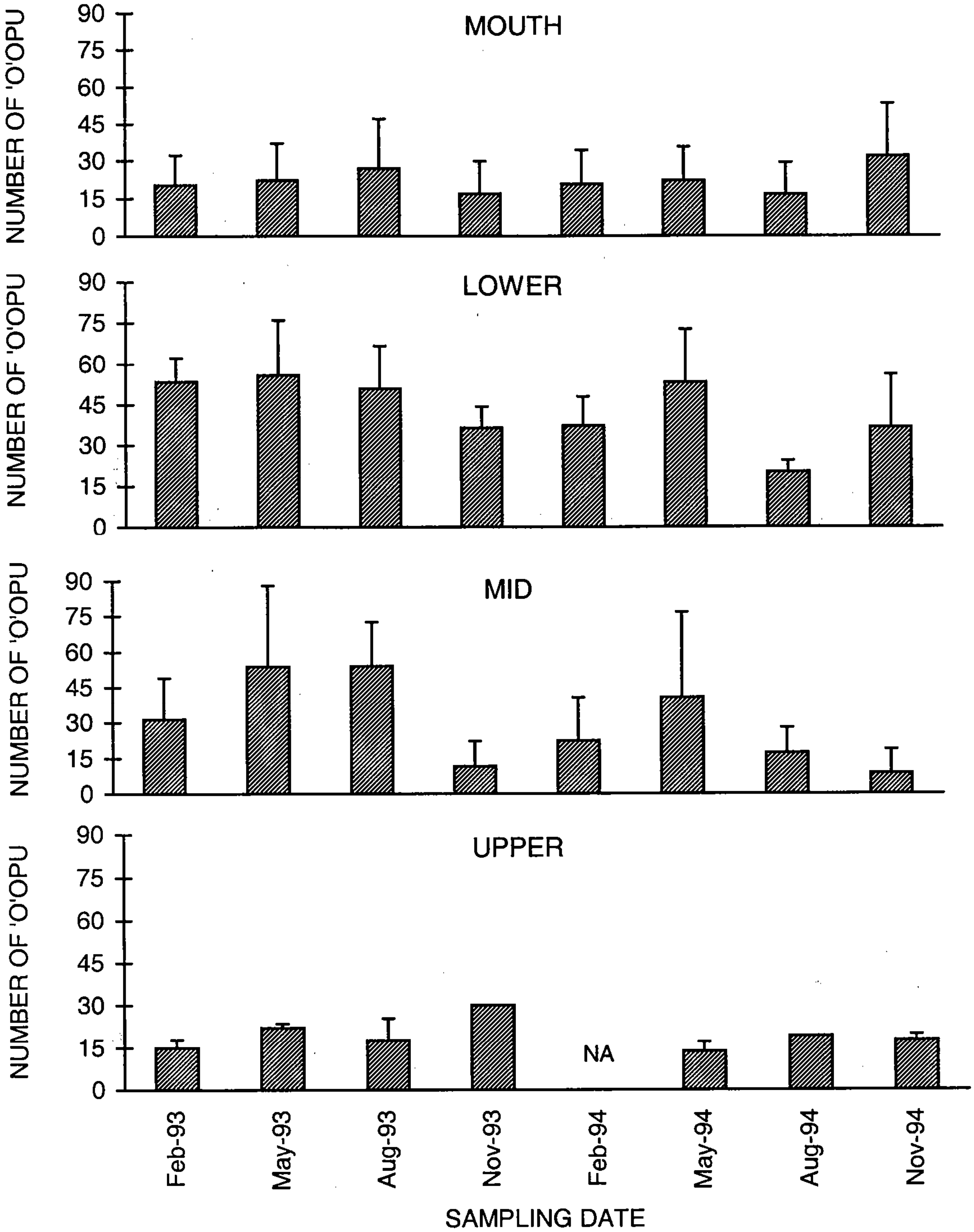


Figure 13. Distribution and abundance of 'o'opu alamo'o in Waikolu Stream during the two year monitoring period. Stations are grouped into four sections: mouth, lower, mid and upper stream reaches. Error bars equal one standard deviation.

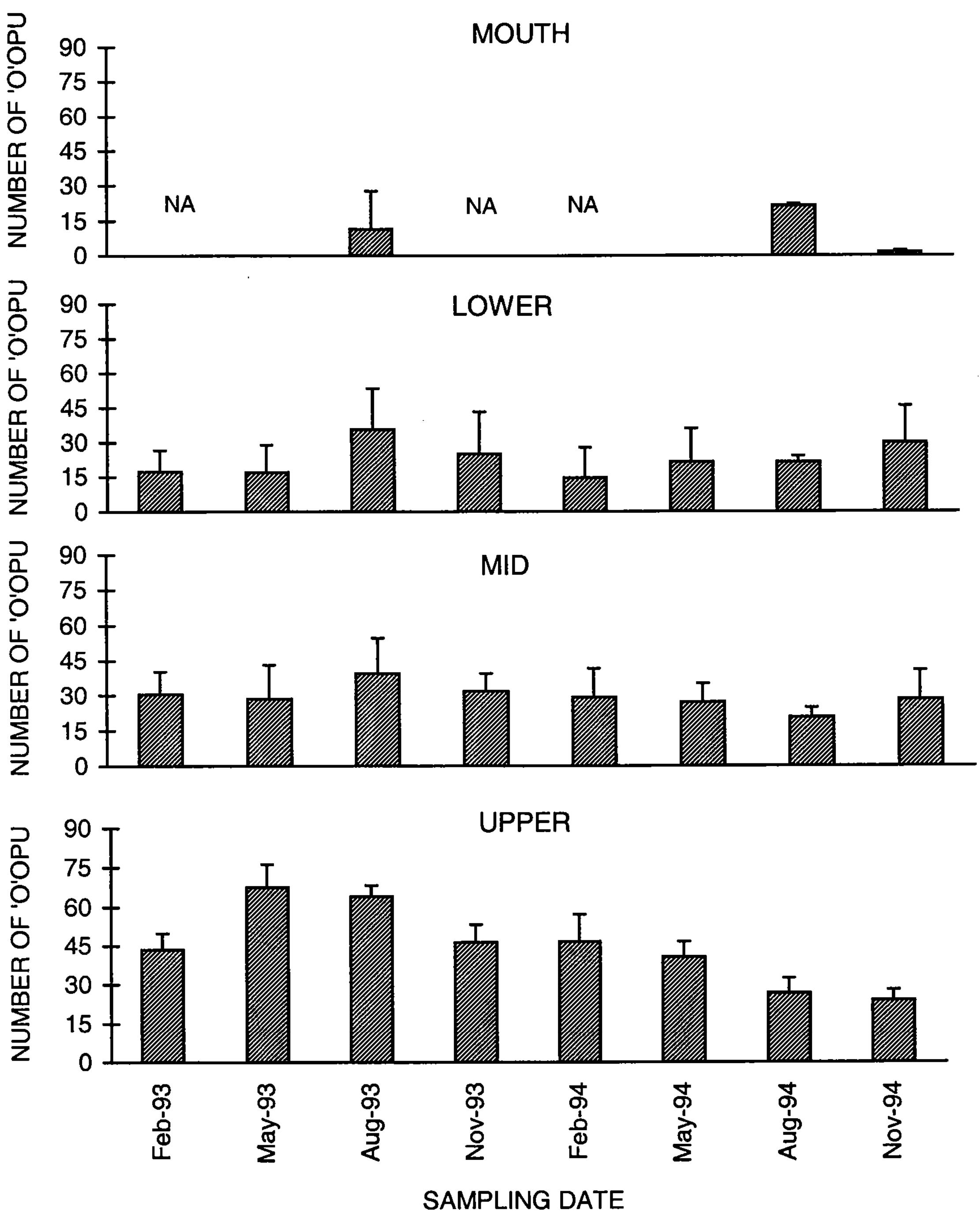


Figure 14. Distribution and abundance of ʻoʻopu alamoʻo in Pelekunu Stream during the two year monitoring period. Stations are grouped into four sections: mouth, lower, mid and upper stream reaches. Error bars equal one standard deviation.

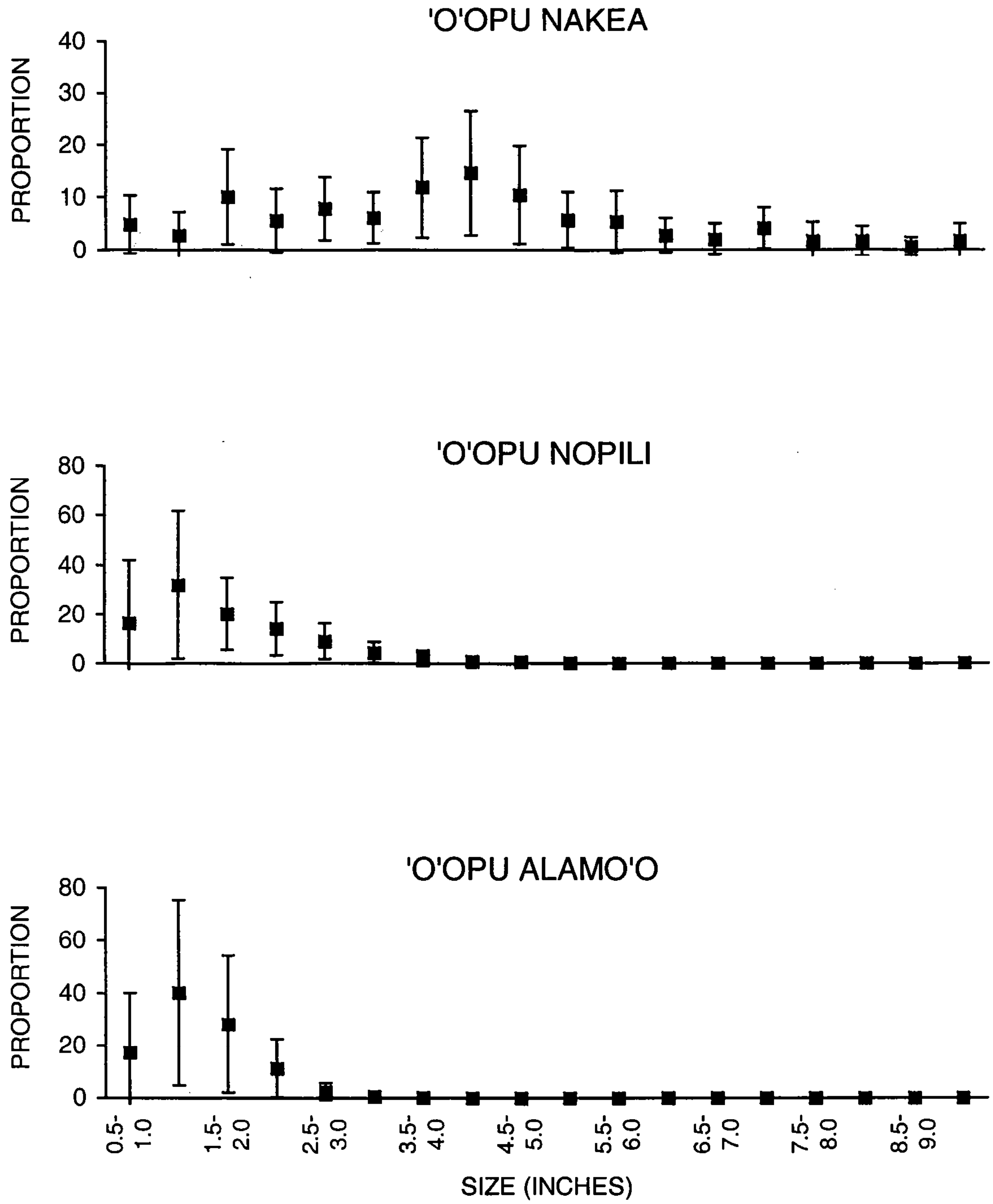


Figure 15. Size distribution of 'o'opu in Waikolu Stream. Proportion of gobies in each size class. All sampling periods combined. Error bars ± one standard deviation.

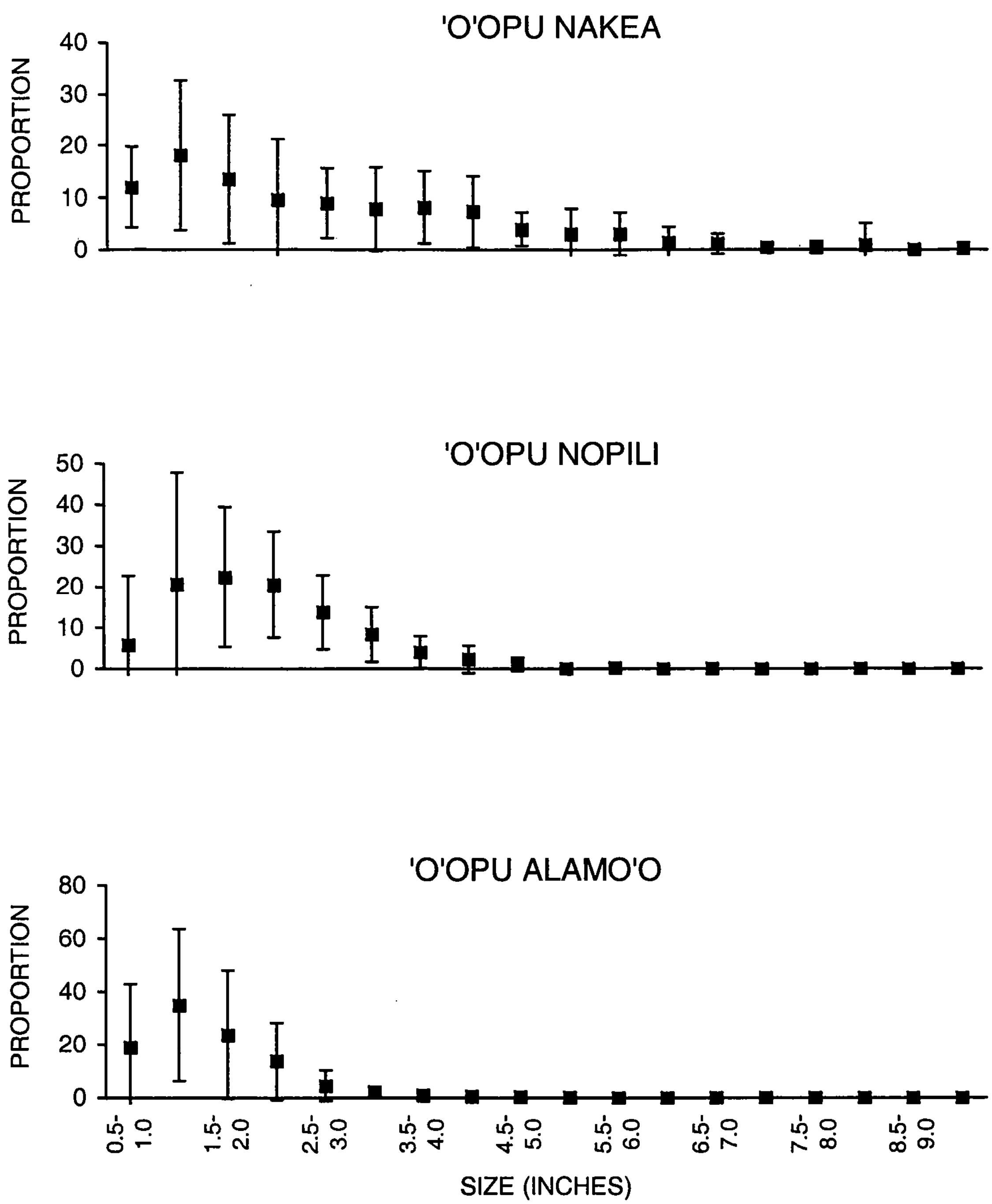


Figure 16. Size distribution of ʻoʻopu in Pelekunu Stream. Proportion of gobies in each size class. All sampling periods combined. Error bars ± one standard deviation.

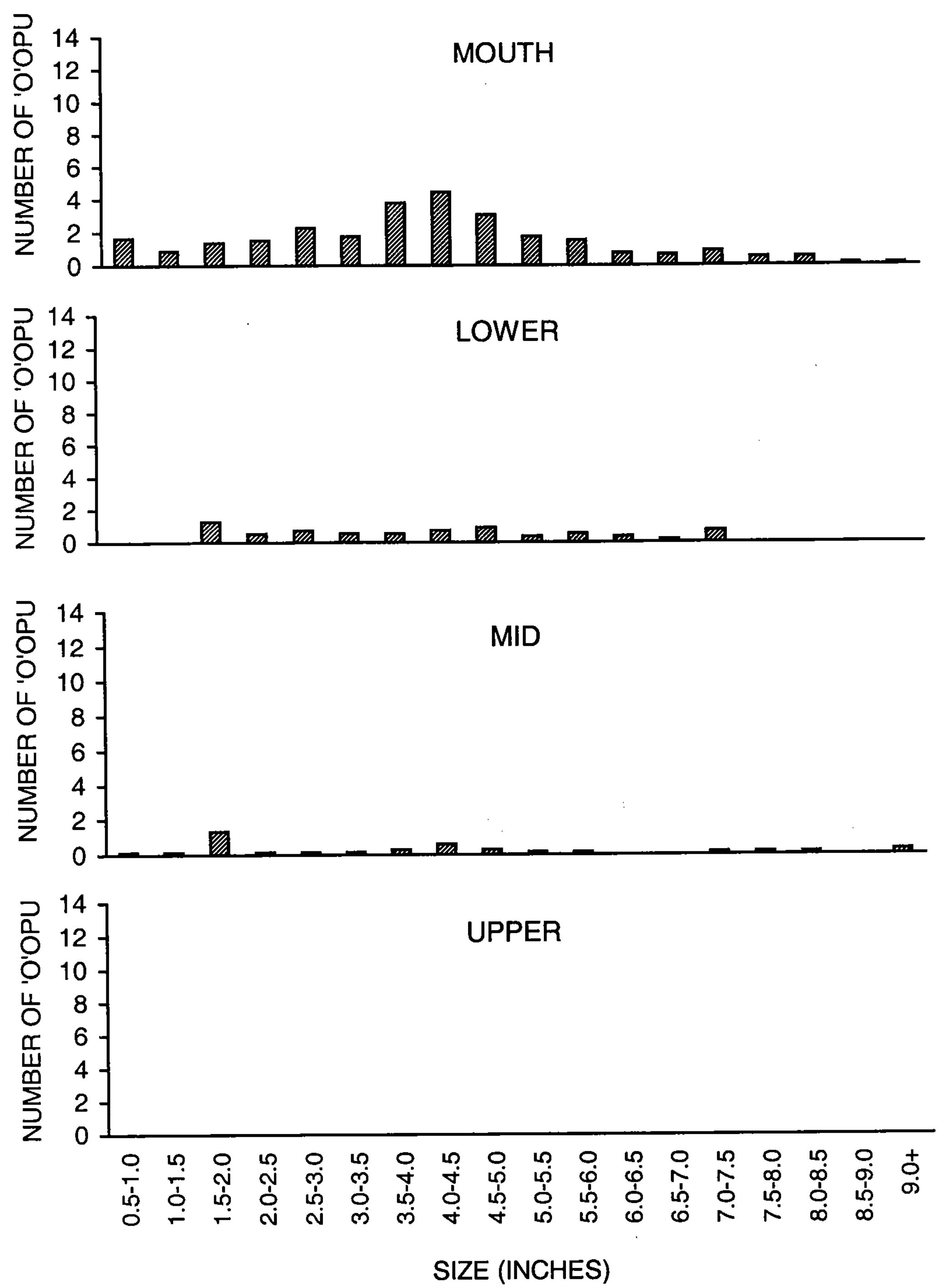


Figure 17. Size classes of 'o'opu nakea along the longitudinal gradient of Waikolu Stream. Stations grouped into four sections: mouth, lower mid and upper reaches. Mean number of 'o'opu per section, all sampling periods combined, adjusted for different numbers of samples at different stations.

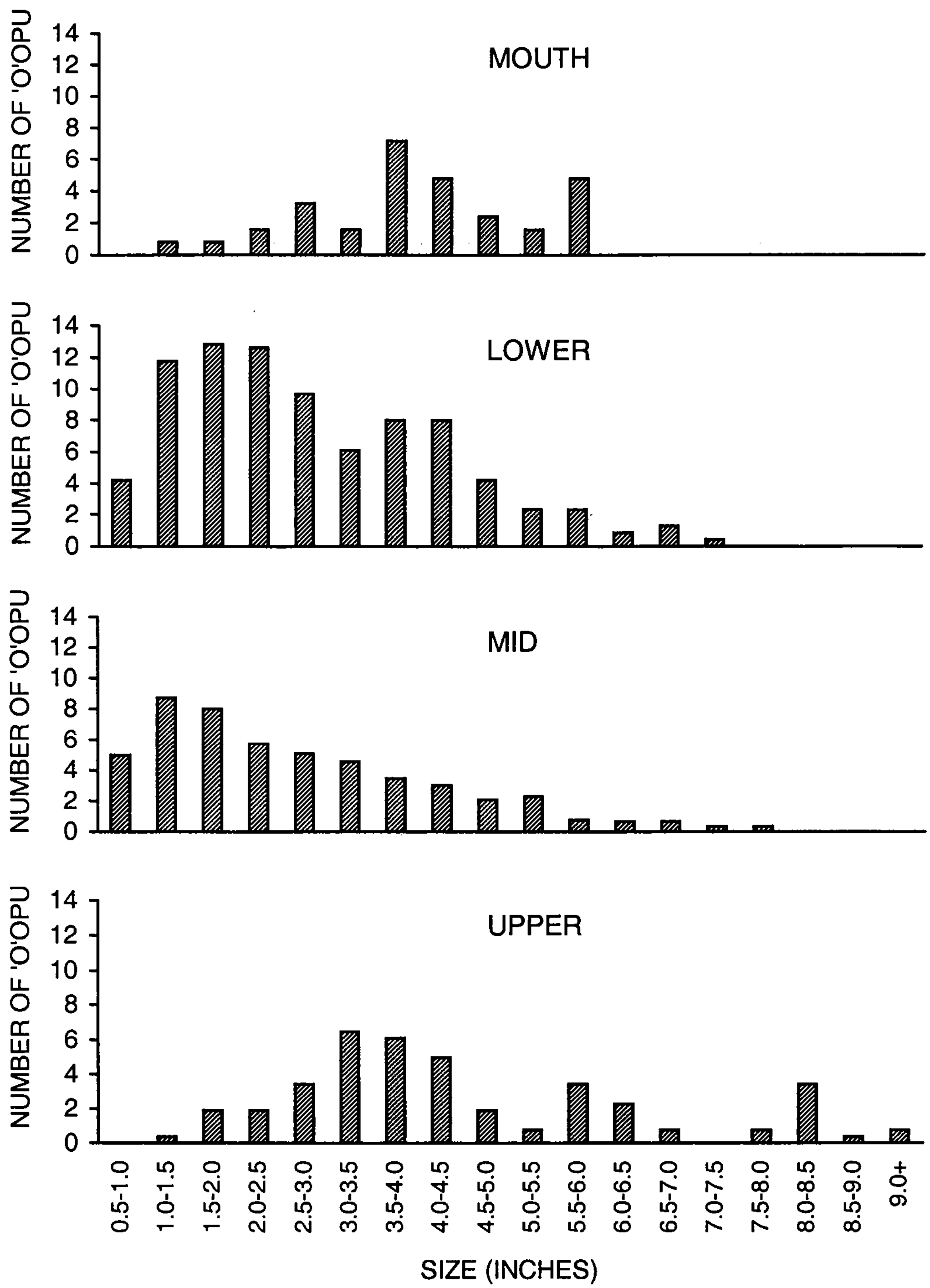


Figure 18. Size classes of ʻoʻopu nakea along the longitudinal gradient of Pelekunu Stream. Stations grouped into four sections: mouth, lower mid and upper reaches. Mean number of ʻoʻopu per section, all sampling periods combined, adjusted for different numbers of samples at different stations.

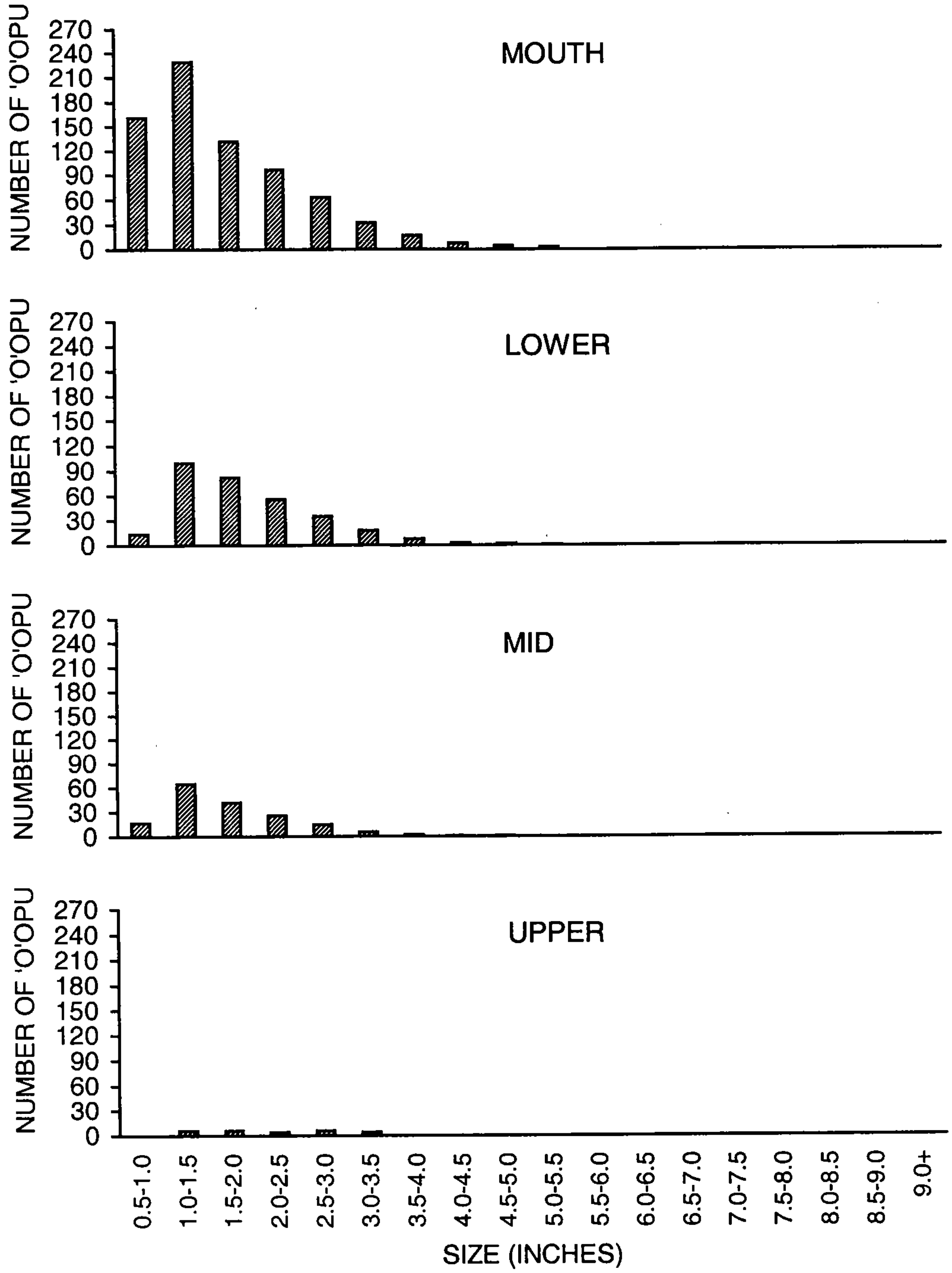


Figure 19. Size classes of 'o'opu nopili along the longitudinal gradient of Waikolu Stream. Stations grouped into four sections: mouth, lower mid and upper reaches. Mean number of 'o'opu per section, all sampling periods combined, adjusted for different numbers of samples at different stations.

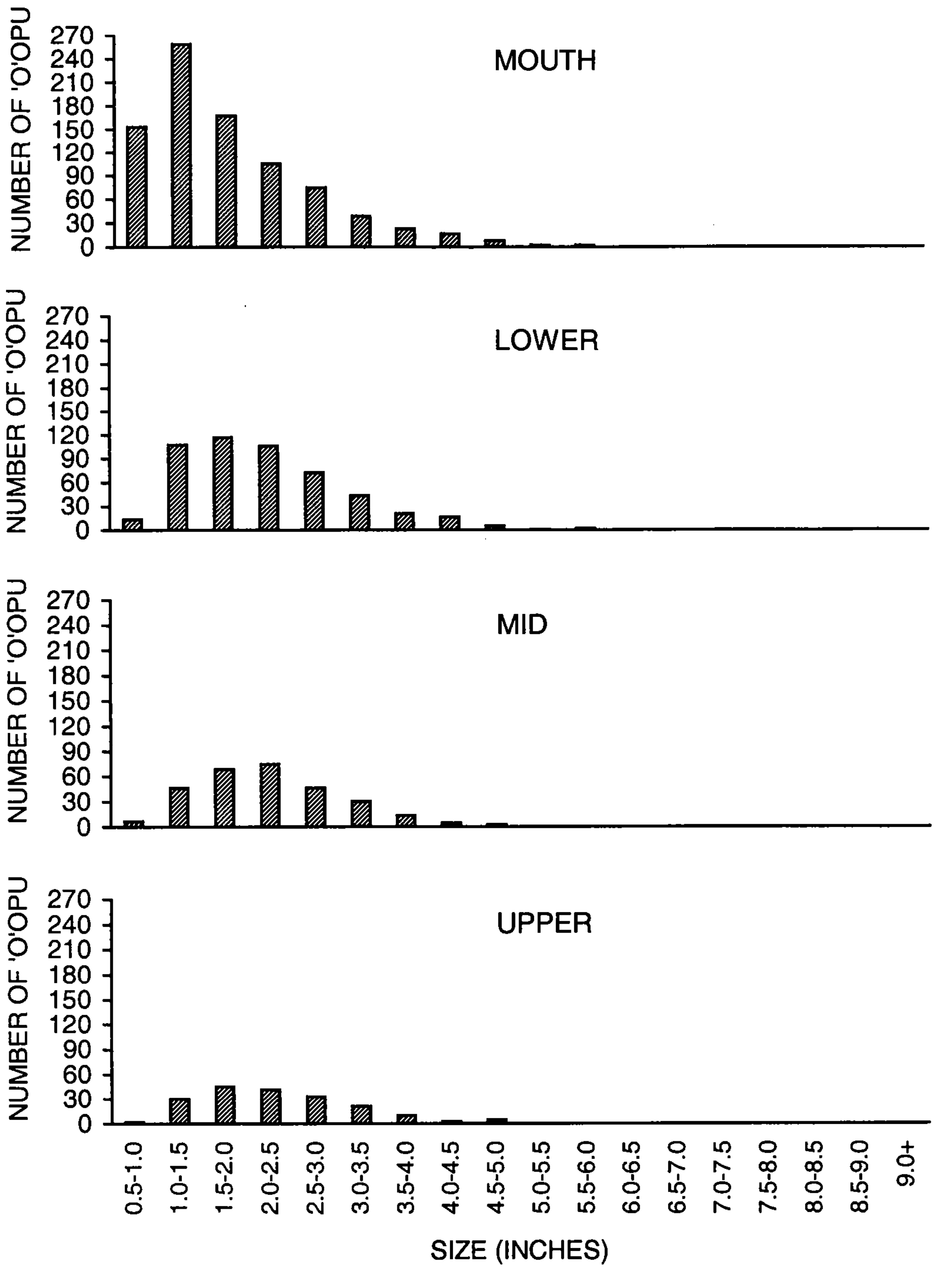


Figure 20. Size classes of 'o'opu nopili along the longitudinal gradient of Pelekunu Stream. Stations grouped into four sections: mouth, lower mid and upper reaches. Mean number of 'o'opu per section, all sampling periods combined, adjusted for different numbers of samples at different stations.

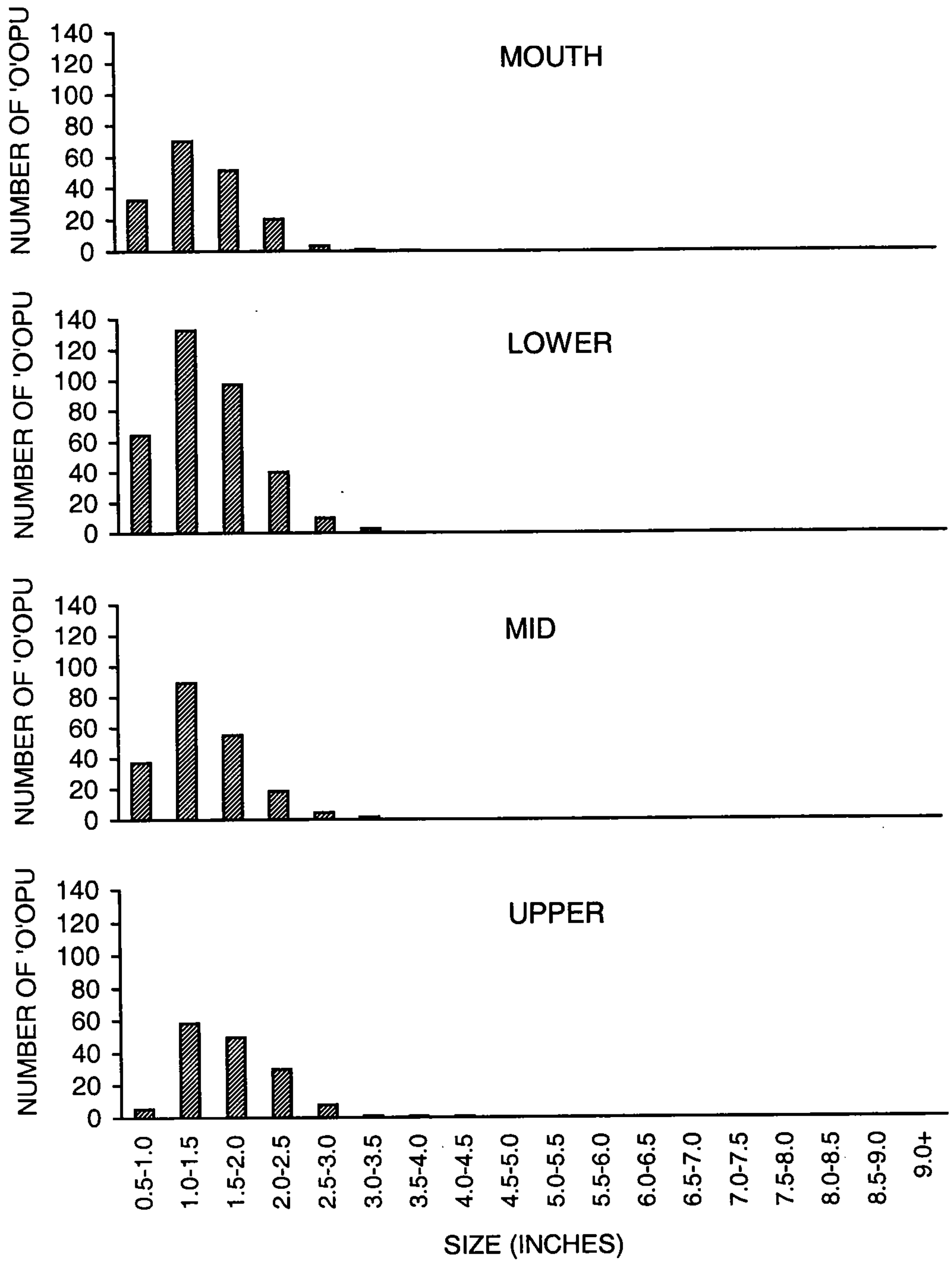


Figure 21. Size classes of 'o'opu alamo'o along the longitudinal gradient of Waikolu Stream. Stations grouped into four sections: mouth, lower mid and upper reaches. Mean number of 'o'opu per section, all sampling periods combined, adjusted for different numbers of samples at different stations.

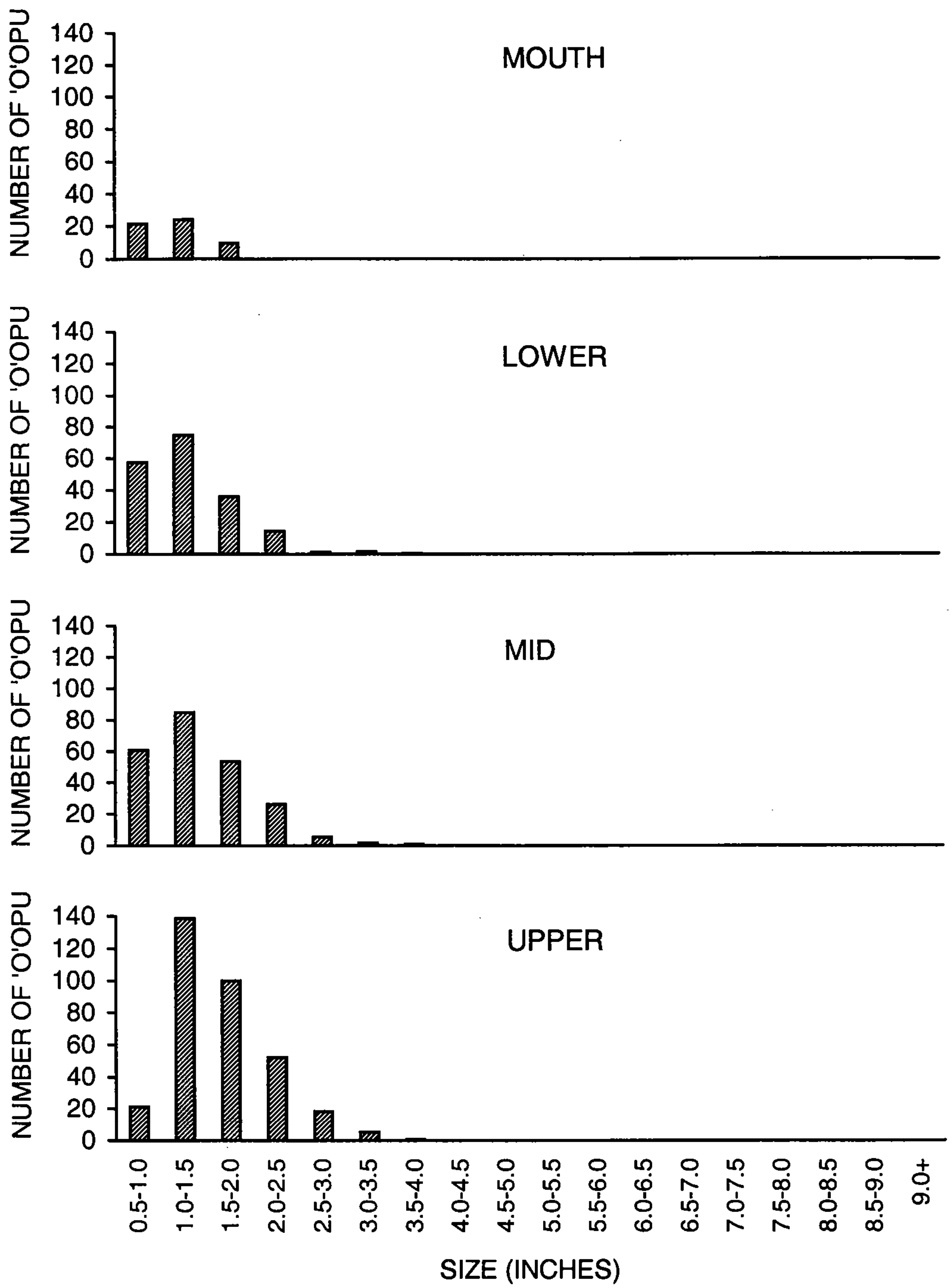


Figure 22. Size classes of 'o'opu alamo'o along the longitudinal gradient of Pelekunu Stream. Stations grouped into four sections: mouth, lower mid and upper reaches. Mean number of 'o'opu per section, all sampling periods combined, adjusted for different numbers of samples at different stations.

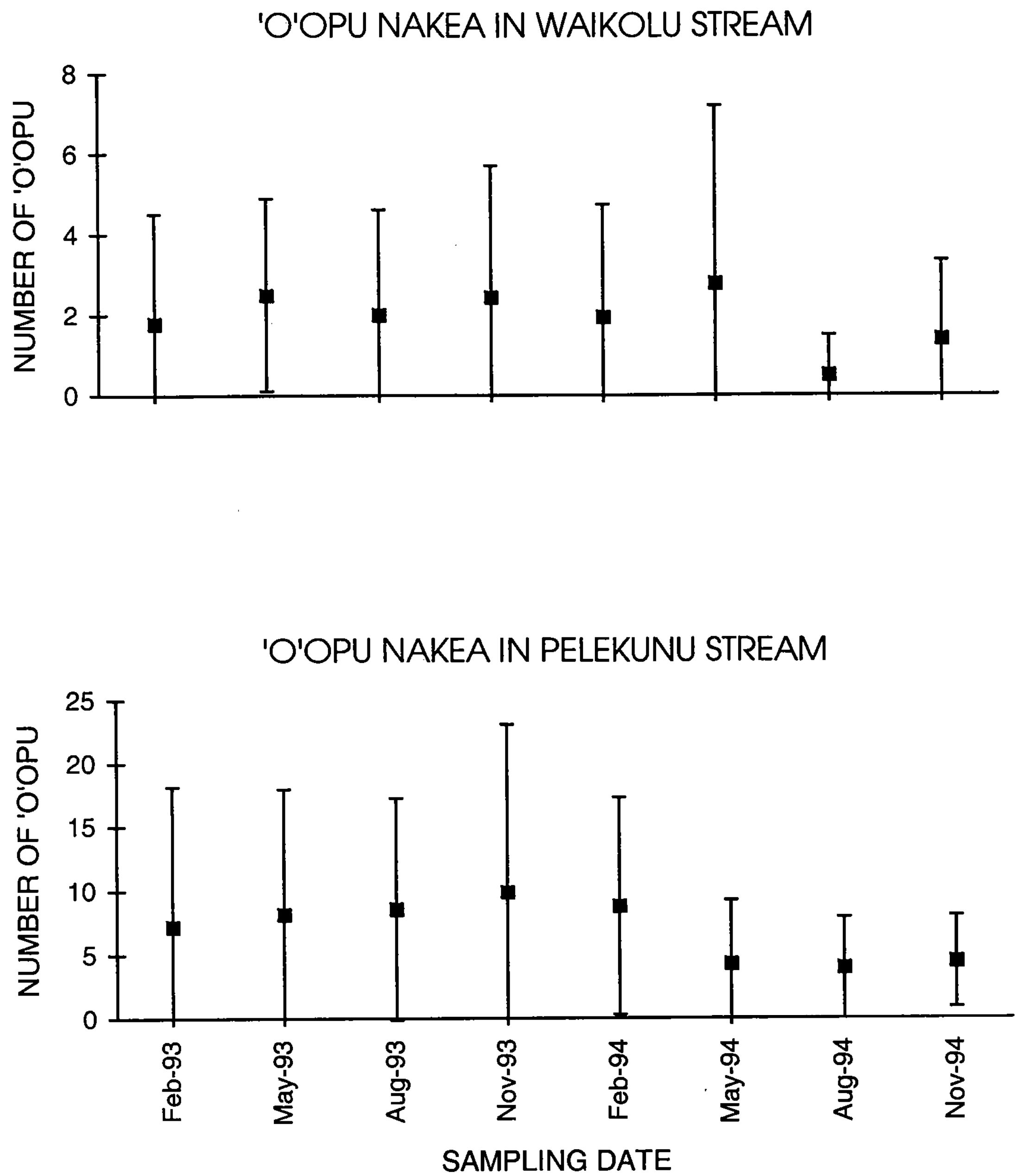


Figure 23. Seasonal change in ʻoʻopu nakea abundance in Waikolu and Pelekunu Streams during the two year monitoring period. Mean number of ʻoʻopu per station at all stations combined (note y axes are different). Error bars ± one standard deviation.

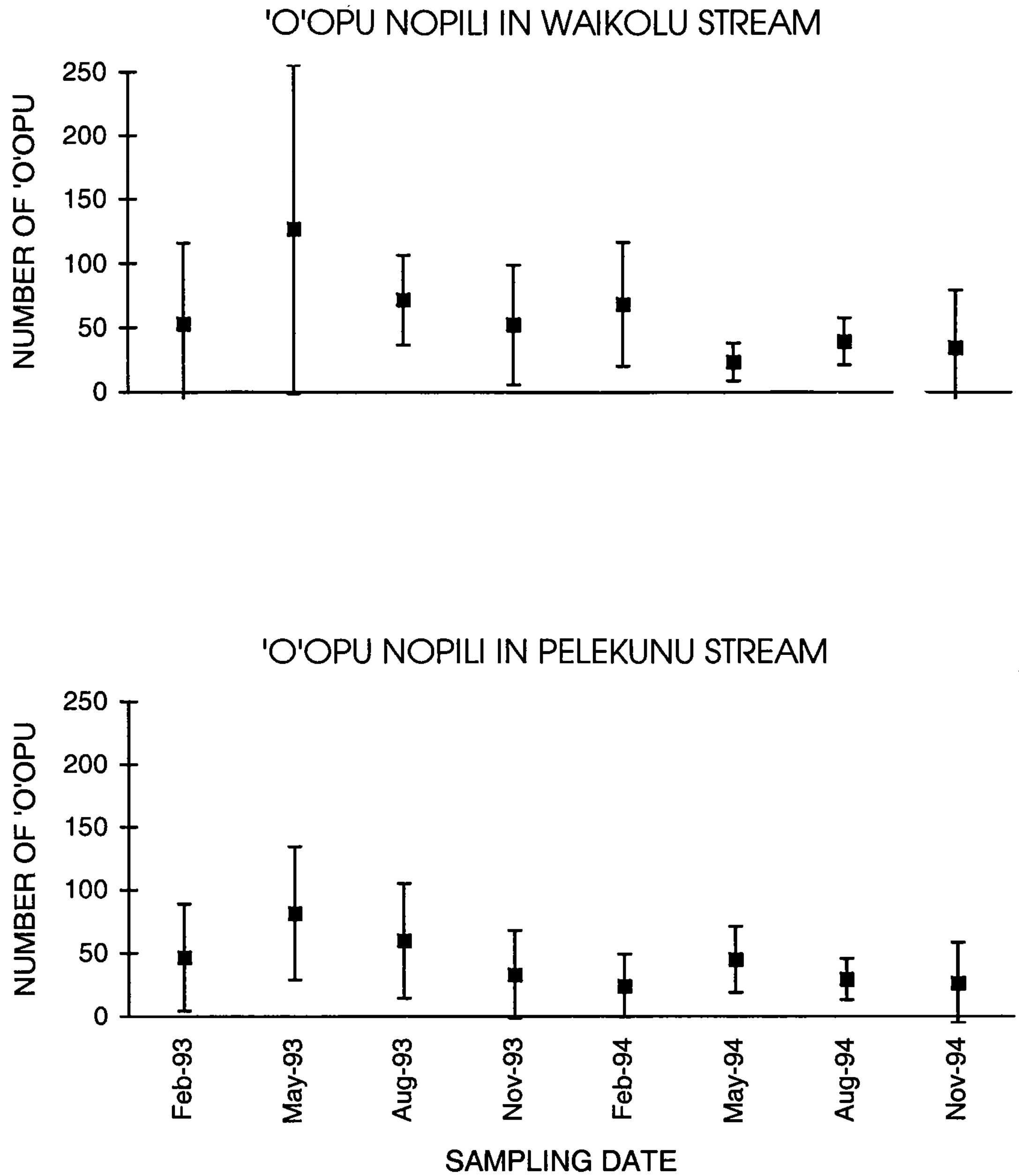


Figure 24. Seasonal change in ʻoʻopu nopili abundance in Waikolu and Pelekunu Streams during the two year monitoring period. Mean number of ʻoʻopu per station at all stations combined. Error bars ± one standard deviation.

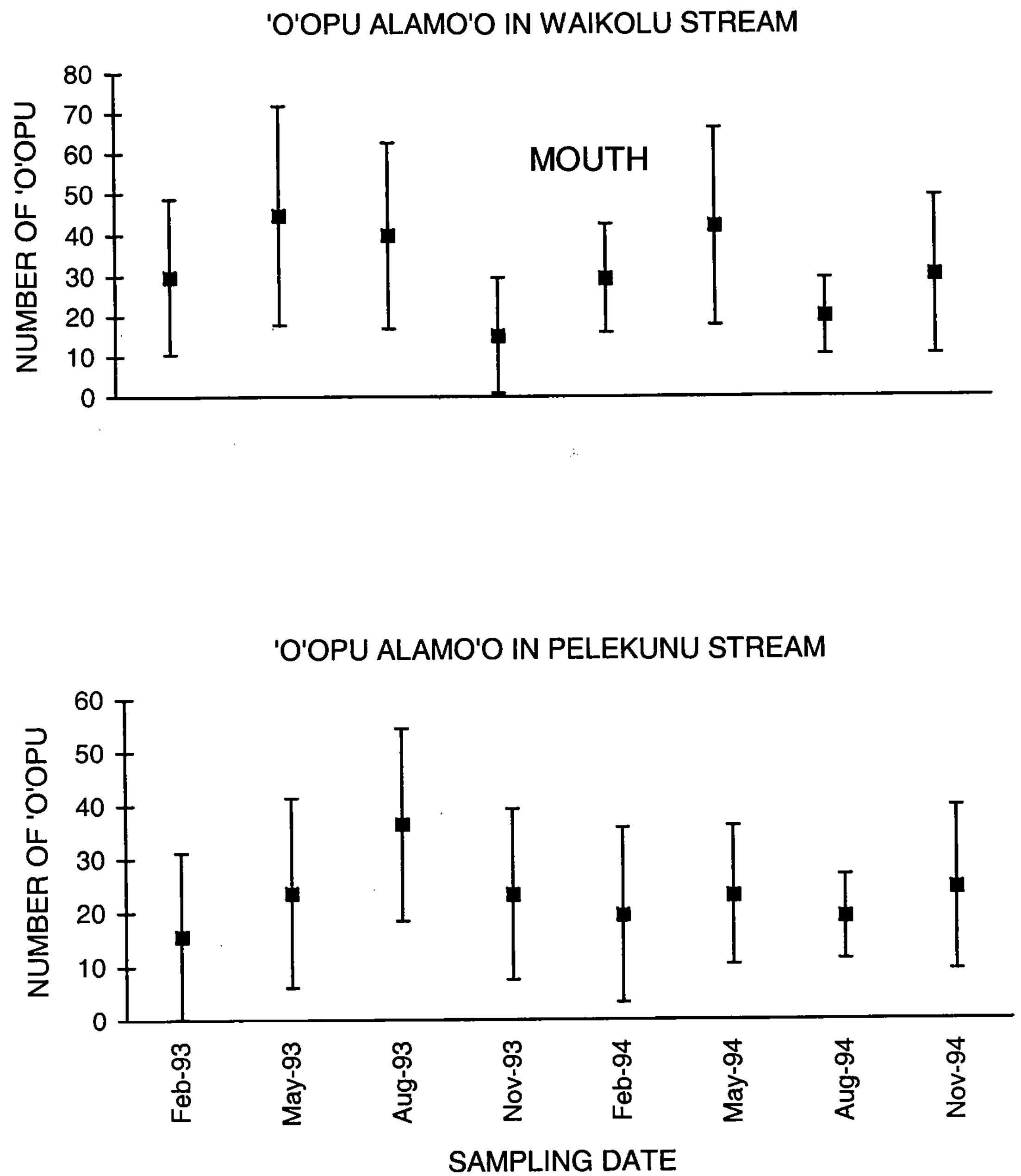


Figure 25. Seasonal change in 'o'opu alamo'o abundance in Waikolu and Pelekunu Streams during the two year monitoring period. Mean number of 'o'opu per station at all stations combined (note y axes are different). Error bars ± one standard deviation.

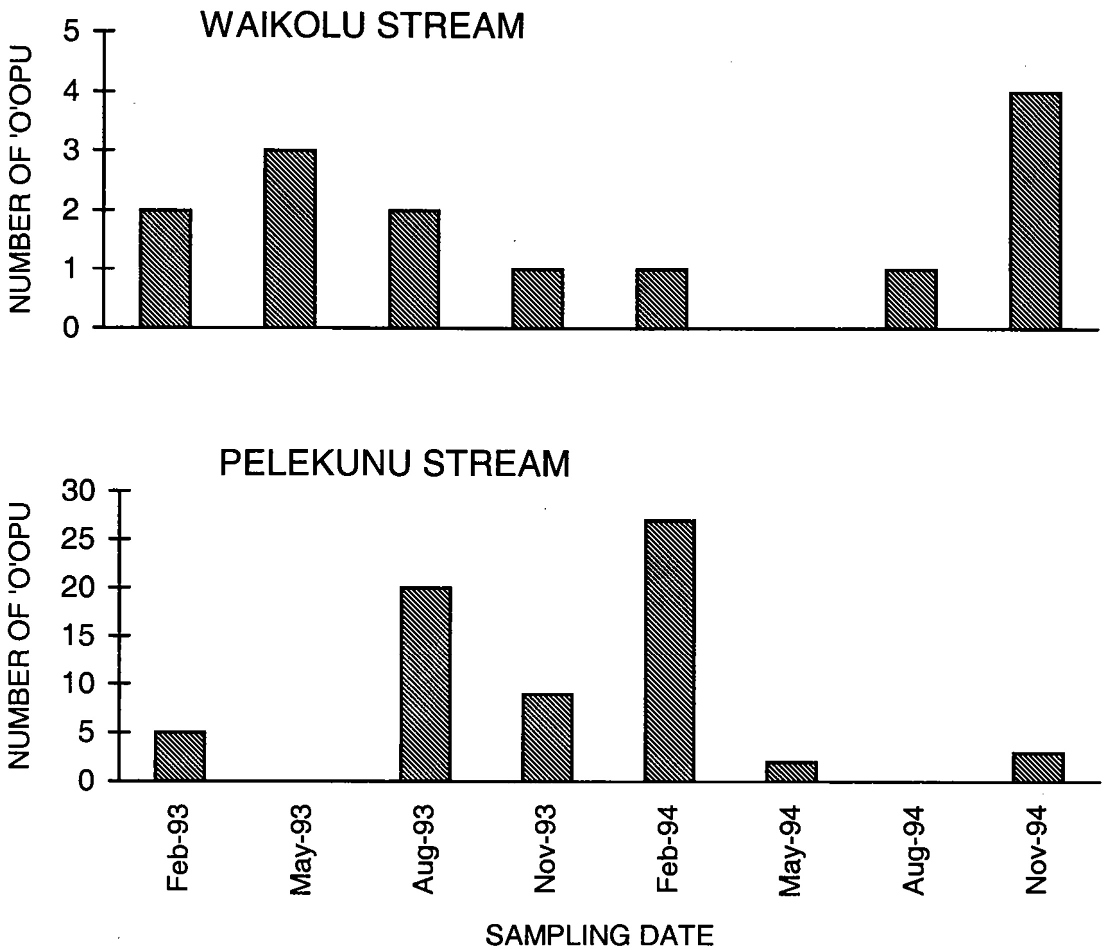


Figure 26. Recruitment (return of post-larval gobies from the ocean to the stream) by 'o'opu nakea to Waikolu and Pelekunu Streams during the two year monitoring period. Total number of hinana at all stations combined. Note that Y axes are different.

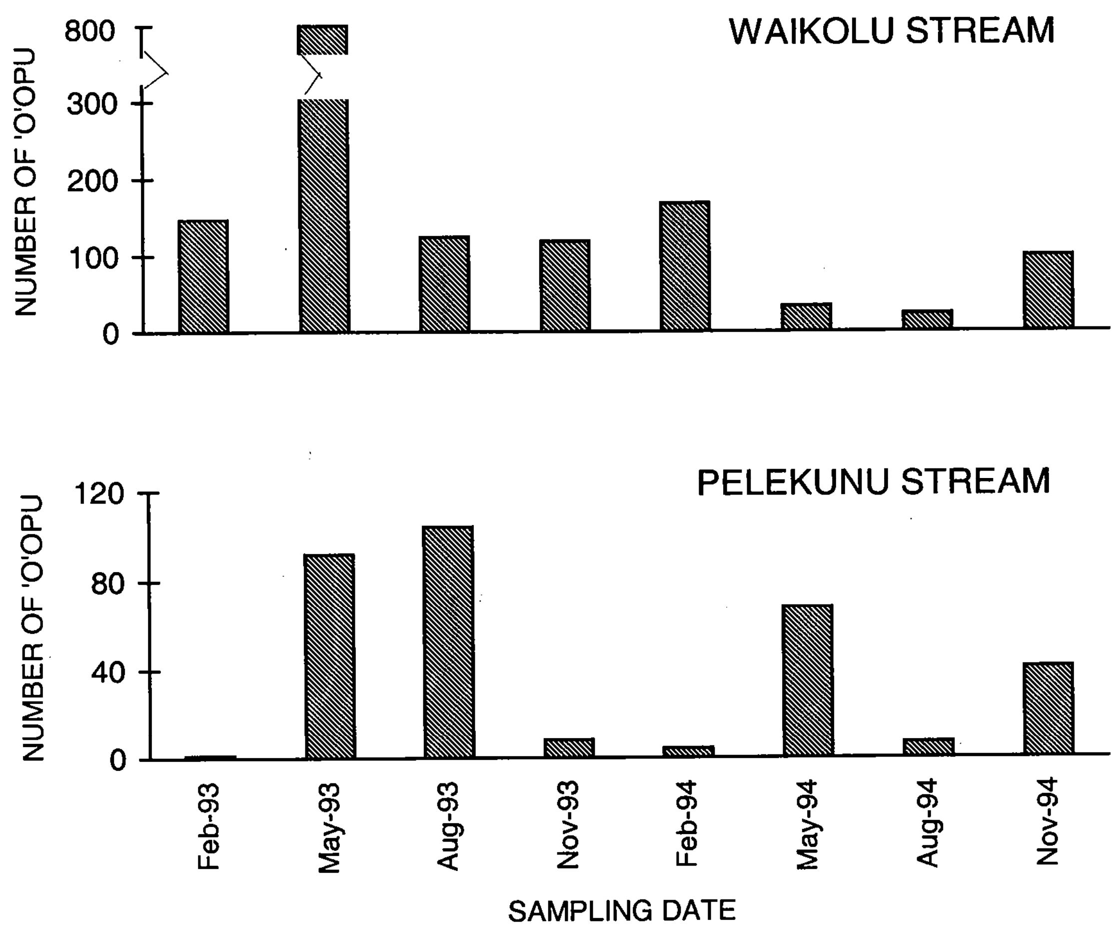


Figure 27. Recruitment (return of post-larval gobies from the ocean to the stream) by \`o\`opu nopili to Waikolu and Pelekunu Streams during the two year monitoring period. Total number of hinana at all stations combined. Note that Y axes are different.

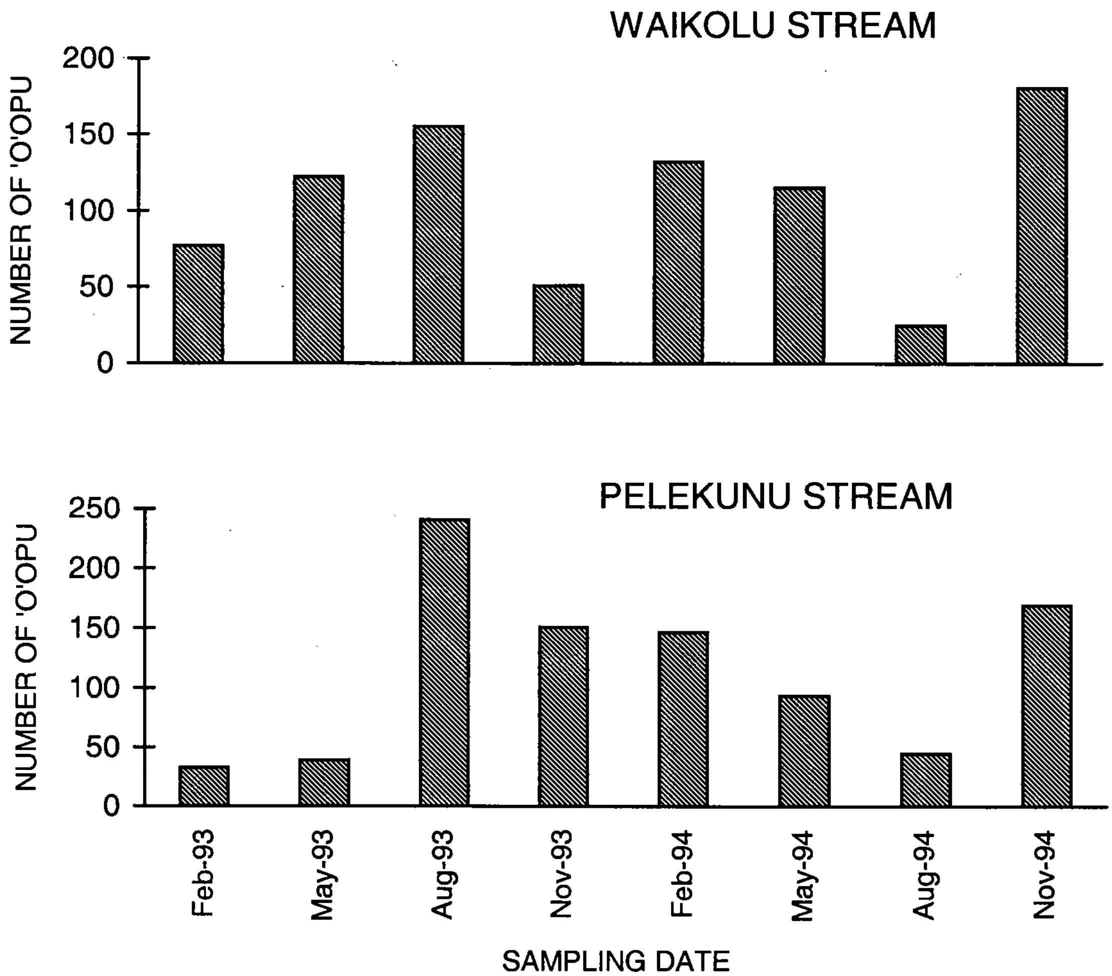


Figure 28. Recruitment (return of post-larval gobies from the ocean to the stream) by 'o'opu alamo'o to Waikolu and Pelekunu Streams during the two year monitoring period. Total number of hinana at all stations combined. Note that Y axes are different.

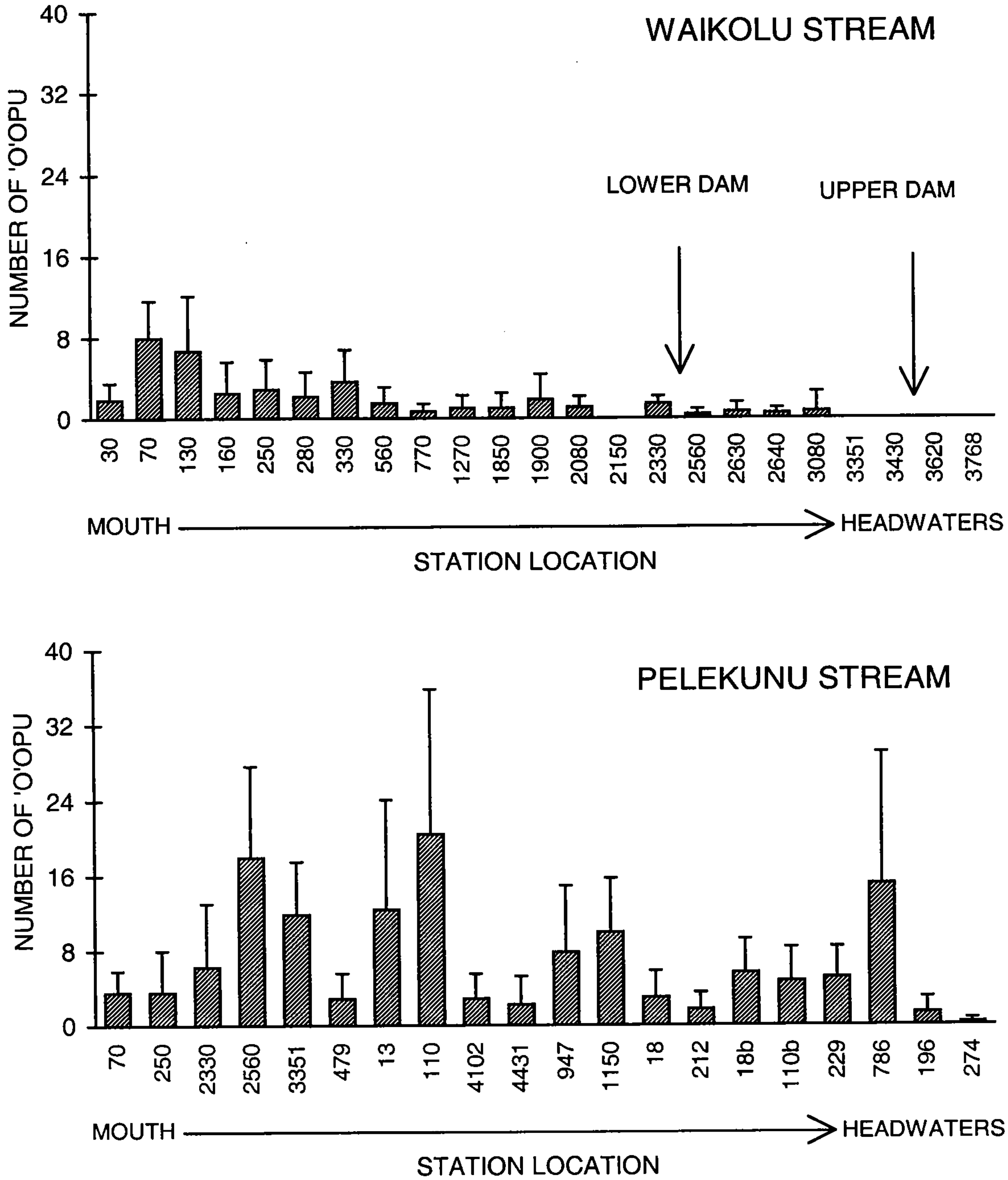


Figure 29. Longitudinal distribution of 'o'opu nakea in Waikolu Stream and Pelekunu Stream. Mean number of 'o'opu per station, all sampling periods combined. Error bars equal one standard deviation.

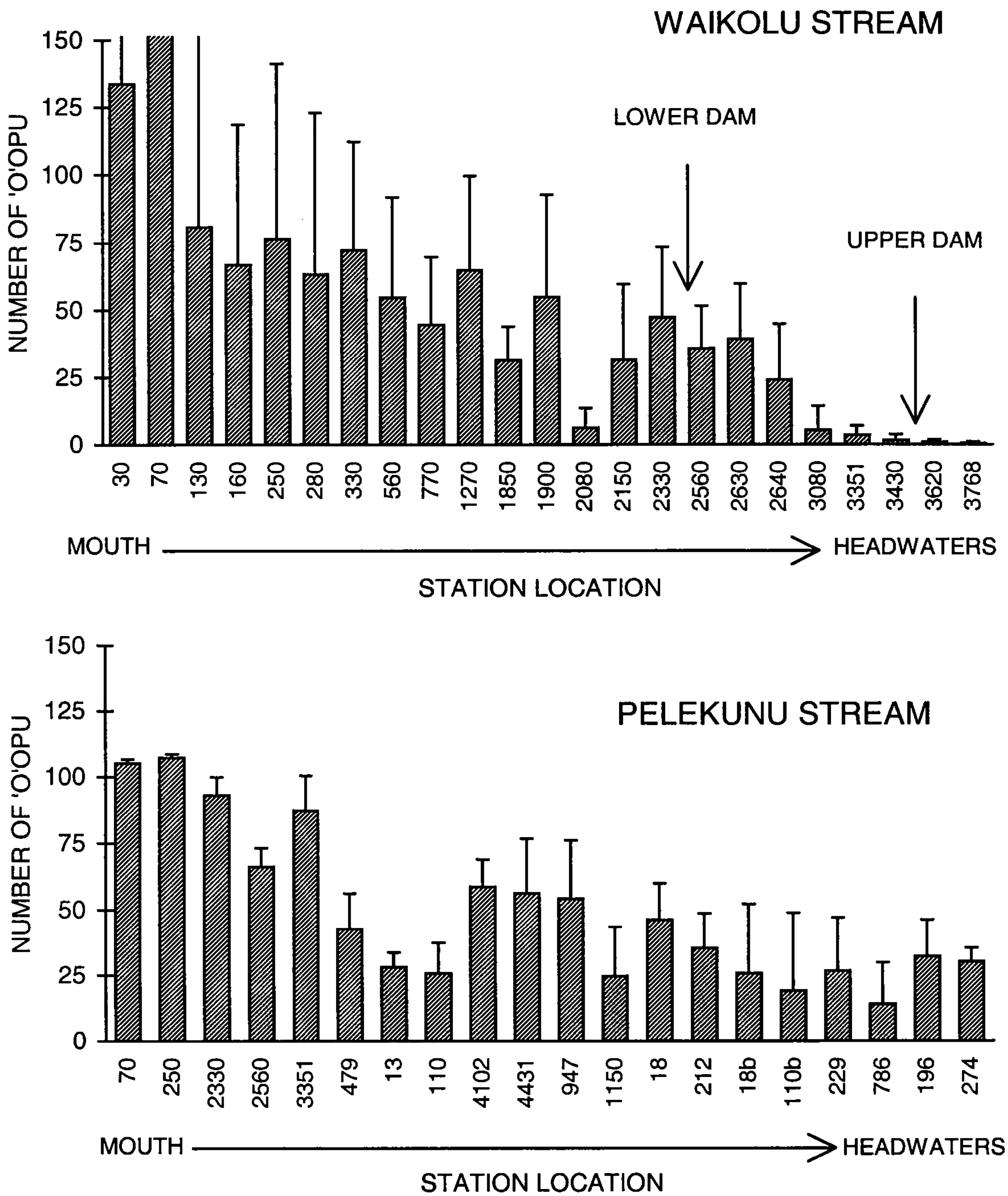
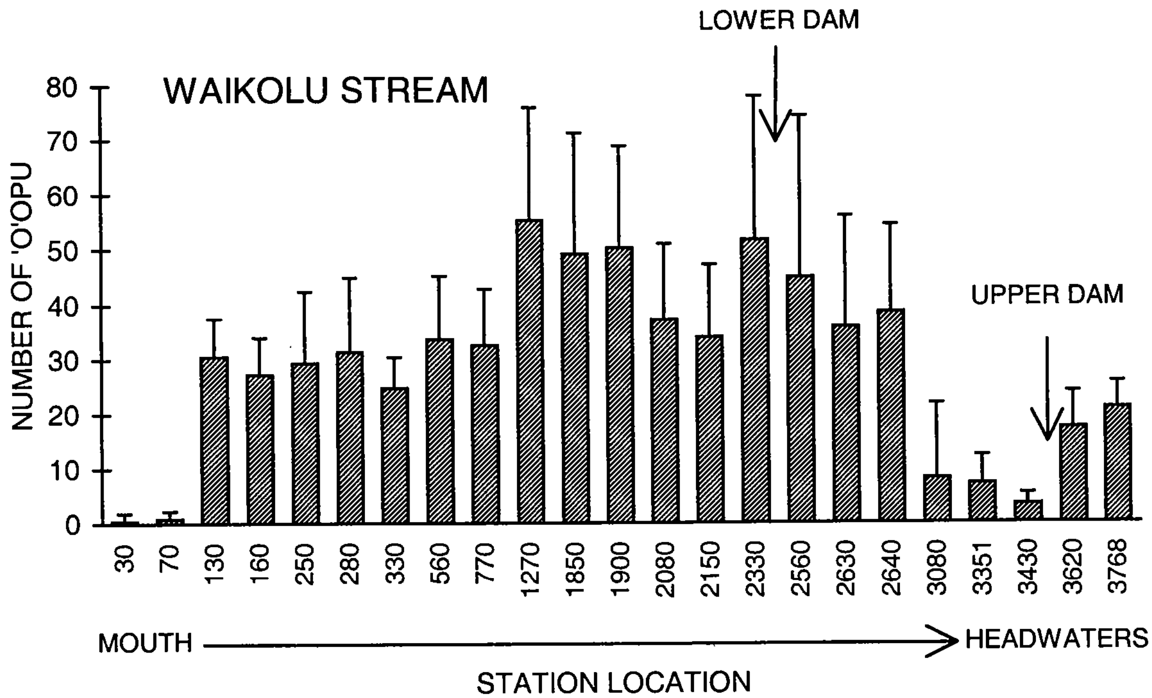


Figure 30. Longitudinal distribution of 'o'opu nopili in Waikolu Stream and Pelekunu Stream. Mean number of 'o'opu per station, all sampling periods combined. Error bars equal one standard deviation.



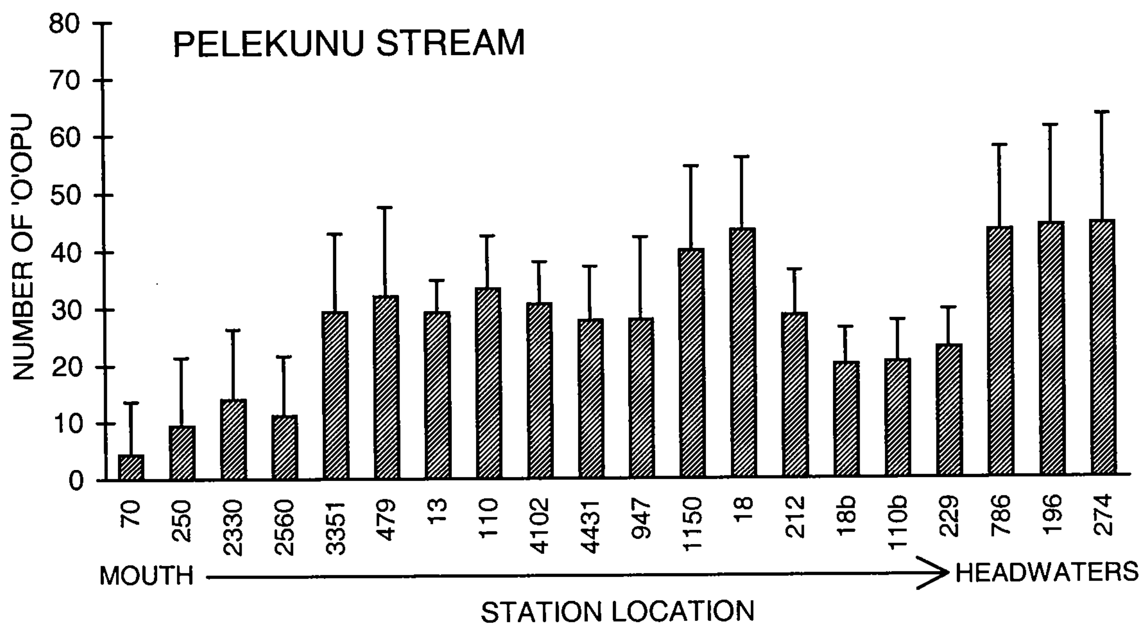


Figure 31. Longitudinal distribution of 'o'opu alamo'o in Waikolu Stream and Pelekunu Stream. Mean number of 'o'opu per station, all sampling periods combined. Error bars equal one standard deviation.

APPENDIX A

Latin and Hawaiian Species Names

CURRENT NAME	FORMER CLASSIFICATION	HAWAIIAN NAME
Eleotris sandwicensis (Vaillant & Sauvage, 1875)	Eleotris fusca	`o`opu akupa `o`opu `oau
Stenogobius hawaiiensis (Cuvier & Valenciennes, 1837)	Stenogobius genivittatus	`o`opu naniha
Awaous guamensis (Eydoux & Souleyet, 1841)	Awaous stamineus	`o`opu nakea
Sicyopterus stimpsoni (Gill, 1860)	Sicydium stimpsoni	`o`opu nopili
Lentipes concolor (Gill, 1860)	Lentipes seminudus	`o`opu alamo`o `o`opu hi`ukole

APPENDIX B

Station and Quadrat Locations

Sampling stations were chosen using a random number table, and located in the stream by pacing off the number of steps equivalent to the number of meters from the mouth. Preliminary work showed that with minimal practice, observers could accurately pace a selected distance in meters.

Ten quadrats were chosen at each station, following a Cartesian coordinate system, again using a random number table. Observers reached each quadrat by pacing off the appropriate number of steps (up, and across) equivalent to meters. For example; a quadrat location of (4,2) would be paced four steps up and 2 steps left (from the origin: 0,0 of the station).

WAIKOLU STREAM

30	160	330	1270
1,7	1,4	0,4	0,7
14,6	4,6	1,5	9,2
16,8	5,0	5,4	12,7
19,6	5,5	6,5	14,8
20,1	10,6	20,6	21,8
21,7	11,6	23,0	26,5
24,6	21,2	24,8	28,0
24,7	23,5	34,5	33,2
26,5	33,2	34,7	33,3
31,7	33,8	36,1	37,4

70	250	560	1850
1,8	0,2	7,5	1,3
3,6	0,8	18,3	5,6
5,2	2,4	21,7	6,1
9,2	5,4	23,0	7,1
10,1	9,5	23,7	11,0
12,2	12,5	24,1	17,6
13,3	15,6	25,5	18,1
18,6	25,4	33,2	18,5
25,4	28,4	33,6	25,6
30,7	33,2	35,3	29,3

130	280	770	1900
0,4	1,8	0,7	1,8
1,5	3,3	1,2	19,1
7,4	6,3	2,6	21,5
23,6	11,8	4,1	24,2
24,2	19,7	10,8	24,6
27,1	24,3	11,6	25,4
33,1	24,8	15,1	26,5
35,1	29,2	20,5	27,7
36,0	30,1	35,7	31,4
37,5	31,1	36,8	36,8

WAIKOLU STREAM

2080	2560	3080	3620
3,7	1,7	1,3	1,4
5,3	6,1	1,5	5,3
11,0	8,6	3,4	14,0
14,6	10,3	4,4	14,4
16,6	12,2	11,5	17,3
22,5	13,0	15,8	19,1
25,0	18,1	16,6	19,4
25,8	22,7	24,2	21,1
27,1	25,4	26,5	31,1
34,0	29,1	34,1	37,4

2150	2630	3351	3768
14,2	0,0	9,7	2,4
20,3	3,4	10,4	5,2
24,3	5,1	12,8	9,2
24,5	7,0	15,4	11,0
25,0	15,5	19,4	12,1
25,1	18,4	22,2	22,2
26,6	20,1	30,7	24,3
27,3	24,3	34,7	29,2
35,5	27,1	35,4	33,1
37,8	37,7	37,4	36,2

2330	2640	3430
0,4	0,3	0,5
11,6	0,5	5,2
13,4	1,0	6,6
18,5	4,0	11,1
23,8	6,8	12,3
24,2	7,2	12,6
26,0	15,2	20,5
28,3	19,7	25,1
33,1	20,2	27,7
33,5	28,6	33,5

PELEKUNU STREAM

70	2560	13	4431
1,8	1,7	1,1	1,2
3,6	6,1	1,3	11,5
5,2	8,6	10,1	12,4
9,2	10,3	15,4	13,6
10,1	12,2	16,4	14,4
12,2	13,0	31,2	15,3
13,3	18,1	38,4	16,4
18,6	22,7	40,4	17,1
25,4	25,4	44,1	25,6
30,7	29,1	69,3	29,8

PELEKUNU STREAM

250	3351	110	947
0,2	9,7	10,1	2,0
0,8	10,4	19,0	2,3
2,4	12,8	24,2	12,1
5,4	15,4	28,1	29,6
9,5	19,4	31,2	32,0
12,5	22,2	35,1	33,1
15,6	30,7	38,0	33,2
25,4	34,7	47,4	40,4
28,4	35,4	58,4	43,5
33,2	37,4	63,3	46,5

2330	479	4102	1150
0,4	1,4	4,9	1,0
11,6	1,5	5,7	2,3
13,4	16,2	15,5	3,4
18,5	19,3	20,9	4,4
23,8	24,6	21,2	19,1
24,2	31,0	21,7	21,1
26,0	38,1	24,9	27,4
28,3	38,4	27,0	36,4
33,1	40,5	31,9	45,1
33,5	47,0	33,6	48,4

18	110b	196
14,0	4,0	18,1
15,2	6,4	19,4
19,0	20,2	21,3
24,0	28,2	25,4
27,2	33,0	31,1
28,4	45,3	43,4
29,2	46,3	44,1
35,3	47,0	59,3
38,6	66,1	62,4
40,2	67,3	66,4

212	229	274
18,1	0,0	5,2
19,4	11,0	5,3
21,3	15,3	16,4
25,4	19,1	24,3
31,1	23,4	25,0
43,4	37,2	25,1
44,1	39,4	27,3
59,3	52,1	28,2
62,4	52,4	33,1
66,4	56,0	38,4

PELEKUNU STREAM

18b	786
4,0	1,0
6,4	2,3
20,2	3,4
28,2	4,4
33,0	19,1
45,3	21,1
46,3	27,4
47,0	36,4
66,1	45,1
67,3	48,4

APPENDIX C

Stations assigned to mouth, mid, lower and upper sections

MOUTH

WAIKOLU	PELEKUNU
30	70
70	250
130	
160	
250	
280	
330	
560	

LOWER

WAIKOLU	PELEKUNU
770	2330
1270	2560
1850	3351
1900	479
2080	13
2150	

MID

WAIKOLU	PELEKUNU
2330	110 (Pilipililau)
2560	4102
2630	4431
2640	947
3080	1150
3351	18 (Pelekunu)
	212
	18b (Kawailena)
	110b (Kawainui)
	229

UPPER

WAIKOLU	PELEKUNU
3430	786
3620	196
3768	274